Adaptive methods for the halftone improvement in conventional screening techniques

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Abstract: Non-periodic dot placement of the variety of so-called FM screening techniques results in greater NSR of the grey scale rendition and, hence, in lower printability as compared with a prevailing in commercial use regular halftone pattern. From the other hand, the finite screen ruling of the periodic halftones limits the definition of a printed image keeping it over a century, since the times of the halftoning invention, about ten times inferior to that of the plate making and printing processes. Nevertheless, the digital picture processing of today provides the facility to selectively modify the geometry of the microdot placement in a periodic screen pattern in accordance with the local image area content. That improves the picture sharpness and definition while preserving the printability (grey scale rendition) of a halftone structure for the stationary image area. Our patented adaptive screening approaches provided on the basis of the normal and excessive volumes of an input pictorial data are described here with comparison to the other high frequency filtration techniques and screening error corrections.

Introduction

Imaging systems enabling creating just two levels of an optical parameter (optical density, brightness, luminance, reflectance, etc.) are now widely used not only in the graphic arts technology, but in electrophotography and thermography, ink jet printers and LCD displays as well. To simulate intermediate, grey levels on the halftone image of a continuous tone (CT) original the screening is used. It is performed due to variation of the relative area occupied on a copy by the printed and blank elements. Steadily and uniformly provided minimal sizes of these elements have finite values, which are determined by the resolution of a given ink-paper-plate system, i.e. depend on properties and specific of these components interaction in printing process. Taking into account the finite minimal size of halftone dots, frequency of their placement on a substrate can't be too high for there should

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be provided the sufficient range of these dots area variation to reproduce the desired amount of gradations. As far as halftone dots, themselves, destroy fine details and contours of an image, the finite screen ruling value limits the definition and sharpness of a halftone as compared with a print for the line work (LW) or a photograph.

Screen frequency should have some optimal value to match the conflicting demands of both spatial and tonal resolution for the particular printing conditions. As a criteria for such optimization there was suggested the relative area (%) of a minimal available halftone dot (Kuznetsov, 1999). More than a century practice of the halftoning shows that this value is approximately constant for all the variety of rulings within their most common range of 60 -200 Lpi and that's why it was considered as the numerical expression of an empirically found compromise in matching those dissimilar picture properties.

Compromising nature of the halftone principle over a hundred years keeps the printing system properties non conformed both with the properties of an input continuous tone source and with those of a printed image recipient at the output. There was indicated (Kuznetsov and Alexandrov, 1997) that CT original contains certain data which could be transferred by a printing process and appreciated by a viewer but are however lost at a screening stage due to the imperfection of halftoning. The latter reproduces fine details and contours at 5 - 10 fewer resolution of that provided by the same printing technology for the line work. For example, a 1000 dpi of a printer resolution provides the minimal individual element of 25 microns, which corresponds to 4% dot of 200 Lpi halftone. The latter reproduces, in its turn, without the lost of a contrast, just about a 100 cycles per inch frequency of the CT original if the latter is presented in digital file at definition of at least 400 ppi. From the other hand, the halftone print objectively includes some of an original data which stays unused by a viewer due to his vision restrictions. This is concerned, for example, with the excessive multi level (formally of 256) presentation of fine detail density or color. Though, optimal image encoding techniques and color TV practice confirm that just a few levels there would be sufficient.

To satisfy the contradicting demands for resolution and tone rendition improvement the principle of an optimal screening can be used (Kuznetsov and Uzilevsky, 1976). Such a screening changes its properties selectively, depending on the image local area content, to match to a fewer or to a greater extent this or the other of the above demands. Psycho-visual premise of an adaptive approach here, as well as for the number of techniques for optimal encoding of CT images, is enclosed in the substantial decrease of the contrast or threshold sensitivity of vision with the image spatial frequency growth.

In graphic arts reproduction technology the spatial sampling of an image has place at least twice. The first time it occurs at the stage of an initial digital encoding of a

CT original, while at the second time it is concerned with the screening process. Each of these samplings is accompanied by the low pass filtration, i.e. by distortion and loss of the high frequency spectral components of an input pictorial data. That results in decreasing of the overall image sharpness and definition as well as of the geometric accuracy of its contours and fine details. It should be, nevertheless, noted that share and specific of each of the samplings in the output image quality deteriorating are rather different.

The variety of high frequency correction techniques is used to compensate this low pass filtration. Some of them are applied to the multilevel pictorial data before the screening stage. The other are provided to minimize the specific distortion of the halftone process and that's why modify its performance during bit map formation in the electronic dot generator, RIP or software application. Being, in fact, intended for the same common objective, some of these techniques compensate the effect of each other. Meanwhile there are the methods correcting just a certain kind of distortion and thereby providing the effect which is additive to that of the others.

In following discussion the efficiency of adaptive screening is shown in comparison with some alternative correction techniques both by use of plain imitative geometric interpretations and realistic halftone images.

Correcting the accuracy of fine detail reproduction by increase of the volume of input image data

Halftone dot size, shape and placement geometry are defined by various means. It can be a single «screen hill» (Figure 1a), several hills or dispersed distribution (Figure 1b) of microdot weight values within a screen mesh. As far as these values are in dimension of tone levels, the slices of such distributions on figure 1c - 1h and figure 2 directly comprise the bit maps to control the resulting percent of ink coverage on a print. In combined use of the, so called, spot and threshold functions the first one defines a set of bit maps (halftone alphabet), while the other puts it in a non-linear accordance with the perceptual grey level value to be reproduced. Halftone dot alphabet can be also defined analytically, which provides the flexible facility of scaling the dot dimension at discrete number of screen frequencies and output resolutions. In any of these variants of a screen function presentation the original fine details are subject to destruction. Its result is illustrated on figure 1(c - h) for the contour indicated by the line (1), which separates the fields relating to approximately 94% (left) and 6% (right) of an ink coverage on a print. Models of fig. 2 refer to contour and narrow light strip of an intermediate contrast of 75% and 25%.

Models of figure 1(c, d) correspond to input image encoding with sampling (screening) factor (SF) value of 1.00, i.e. when the encoding sampling period is equal to that of the screen and hence the halftone frequency (Lpi) is the same as the scanned image file definition (ppi). For simplicity of illustration the particular case is chosen when the sampling area (2) coincides with the screen mesh in spatial phase. Value of a sample is 50% because its area is equally divided by contour 1 on dark and light portions at these pictures. So, this part of contour is reproduced by the cross sections of weighting functions of figure 1(a, b) on half of their 64 units height, this sections comprising the 50% halftone dot on figure 1(c) and the uniform field of scattered microdots on figure 1(d).

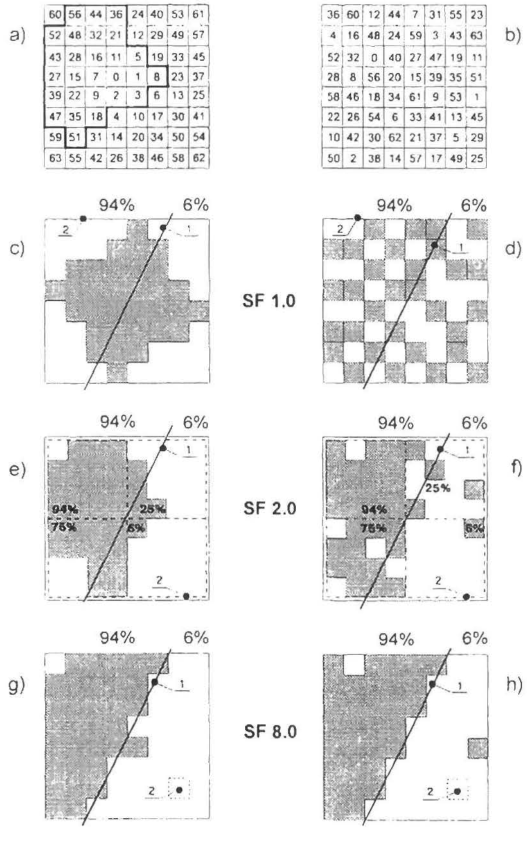


Figure 1. Screen hill (a) and dispersed distribution (b) of microdot weights; halftones of contour (1) at SF values 1.0 (c, d), 2.0 (e, f) and 8.0 (g, h)

With sampling factor of 2.00 the contour becomes to appear in a mesh margins on figure 1 (e, f) for there are as many as four individual samples provided for a single mesh. Their values differ from each other depending on sampling area (2) location in relation to the contour position within the mesh. So, the resulting coverages here are comprised by four quarters of cross sections, each of them being taken at its corresponding level of the screen hill or dispersed distribution of figure 1 (a, b). The latter case is used to be related to, so called, coarse scan / fine print reproduction mode, which is prevailing in printing due to the acceptable volume of scanned data to be processed, stored or transmitted. Nevertheless, further enlarging of the sampling factor results in more accurate reproduction of a black/white transition. Figure 1g and figure 1h demonstrate it for the «fine scan / fine print» mode, when this factor value is equal to 8, i.e. when a solution about each microdot formation is undertaken on the basis of its individual multi level sampling value. Contour of a full contrast is recorded here with the printer or printing process resolution and hence its accuracy is almost the same as for the line work.

It should be noted that such an accuracy is achieved by the use of a hundred times larger volume of an input data because the screen mesh in commercial printing accounts up to 24x24 microdots, instead of 8x8 used for these simplified models. Therefore a coarsely scanned input image is used to be artificially transformed to a finely scanned one at the output stage by means of replication-interpolation procedure (Webb and Kirk, 1988). However, even with such an excess of processed data, especially, when it is provided by interpolation, the screening errors are corrected not so effectively for the thin b/w lines and fine details of sophisticated, like types, configuration or for details of some intermediate contrast corresponding, for example, to coverages of 75% and 25% on figure 2a and figure 2b.

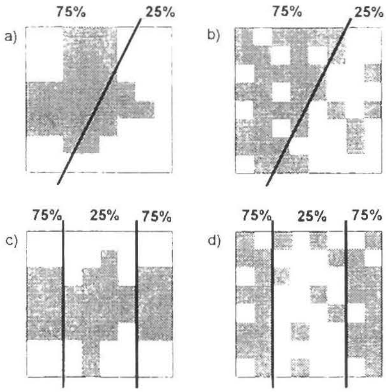


Figure 2. Halftones for contour (a, b) and light line (c, d) of intermediate contrast produced according to screen functions (a,b) of figure 1 at SF of 8.0

Figure 2c shows, in its turn, that the thin light stripe of 25%, which comes exactly through the hill of a screen function, is completely lost, being reproduced by the same amount of microdots on the screen mesh parts relating to this stripe and its 75% dark background. Contrast of the same stripe, meanwhile, is faithfully imaged within the mesh of figure 2d, i.e. irrespective to the position of a stripe in a screen grid, when the weight values distribution of figure 1b is used.

In spite of some advantage for small detail reproduction in fine scan / fine print mode, the unacceptable printability is inherent in dispersed screen function presentation or, as well, in non-periodic microdot placement, which is, by defintion, provided for example by error diffusion screening techniques. The amount of grey levels, which they produce in a continual image area, is far less than that obtained due to the clustered distribution of the kind relating to one shown on fig. 1a. Being non-reproducible individually, the microdots isolated from each other are rarely used in halftoning practice. At least two or four of them usually provide the minimal printable element in highlight, while roughly the same amount of their vacant positions comprise the blank area at the other end of a gray level scale. Moreover, the grey scale rendition in dispersed halftoning is accompanied by appearing of additional covered areas, their number being formally varied from +8 to -4 depending on the individual microdot location in relation to adjacent ones (Kuznetsov, 1998). That results in the noise and dot gain which are additive to that of the plate-ink-paper system. So, for example, at the moment of location in a chessboard fashion the solid is provided instead of 50% grey, though just the half of microdot positions was set dark according to idealistic coverage presentation in a bit-map.

Adaptive modulation of claster frequency in a periodic halftone

It follows from described above that the halftone printability, which is most important for the stationary picture area, should be provided by the regularity of a screen pattern therein. From the other hand, the excess of input data in fine scan / fine

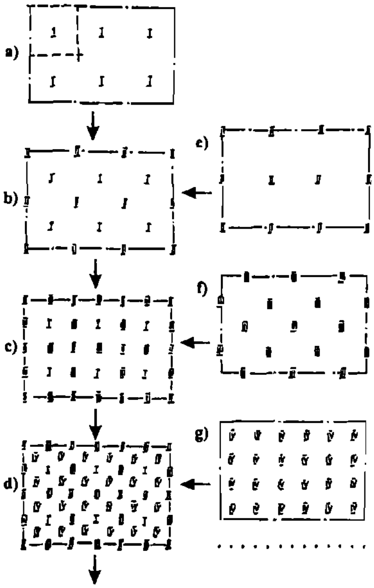


Figure 3. Positioning screen hill centers for the stepwise halftone frequency modulation on contours

print system is not completely used for the image contours and fine details due to low pass filtration resulting from a relatively low ruling of this pattern. That brings to the necessity of an adaptive, according to the local image area content, modulation of a screen frequency.

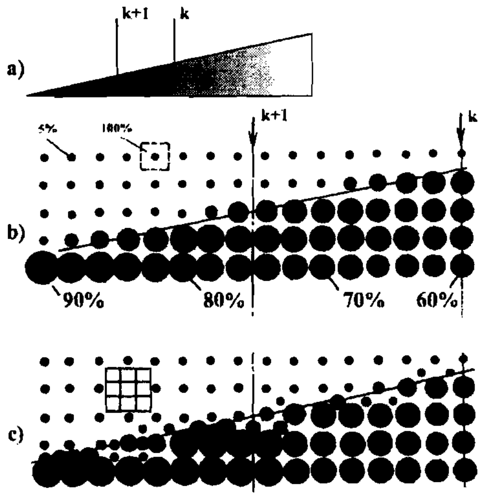


Figure 4. Light/dark transition (a) of continually varying contrast and its reproduction by usual halftone method (b) and with modulation screen frequency in contour origin (c) for basic (I) and auxilary (II-IV) screen functions.

It was suggested, in particular, to vary this frequency stepwise as shown on figure 3 where cluster locations for some set of screen patterns are indicated by the Roman numerals (Kuznetsov and others, 1978). Each cluster in this pattern can be, in its turn, presented by the corresponding matrix of the microdot weights, this matrix dimension decreasing from the pattern of figure 3a to pattern of figure 3d. While the basic coarse pattern of figure 3a is intended for continual parts of an image, the screen ruling is increased with the local picture area busyness growth. Tone value in the contour origin becomes related not only to sizes of halftone dots (Figure 4b) but as well to their amount within the unit picture area (Figure 4c).

Real images include a wide variety of contours. There are, for example, contours of a maximum contrast but with various continuity of transition from lighter to darker part thereof. Contrast and degree of transition continuity may also vary smoothly along a contour. Therefore, just switching over the matrixes of figure 3 according to busyness value can make an image noisy due to the acute alteration of a pattern geometry on the contours and thin lines which gradually loose their strength, as it, for example, happens with contour shown on figure 3a. So, it was proposed to merge the pattern of n-th order into (n-1)th one little by little as the local gradient of grey level increases (Kuznetsov and others, 1982). For this purpose the amplitude of tone value moduli /grad X/ is to be divided on subranges, as shown by the graph 2 of figure 5, each of them being related to one of the structures abcd schematically designated on figure 3. Graph 3 indicates on figure 5 share Y of corresponding additional cluster (structures e, f or g of figure 3) in the overall coverage X predetermined by the input tone value. Each halftone dot, which is inserted by the cluster of n-th order, varies its size XY (graph 4 of figure 5) within the /grad X/ subrange from the minimal printable one up to the value which is equal to that provided by the structure of (n-1) order.

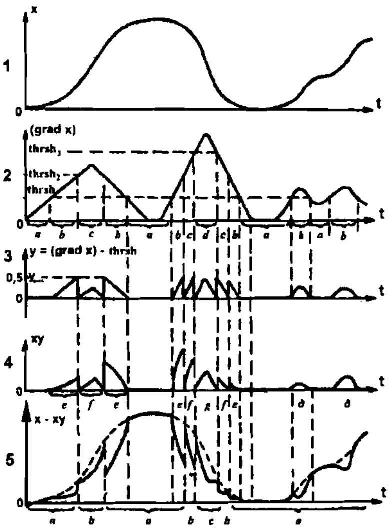


Figure 5. Distributions of tone value (1), of moduli (2) of its gradient, of a share (3) and of a part (4) of tone value related to additional clusters, of a part (5) of tone value related to a pattern of first order

Technique of gradual inserting additional clusters is explained by the model of figure 4c where vertical lines k and k+1 correspond to transition of a contrast value to its adjacent subranges. Cluster of structure of figure 3e starts to be inserted here from the place corresponding to the threshold k, its share being monotonously increased as the point of transition comes nearer to the threshold k+1. Halftone dots, corresponding to clusters of figure 3a, at the same time synchronously decrease their share in the predetermined coverage value until both shares become equal at the point designated by the line k+1. As the strength of a contour continues to increase to the left of the line k+1, the halftone dots generated by clusters of figure 3f begin to participate starting from their minimal printable value. Such a procedure allows for continuous transfer from the operational mode of smooth tone rendition to that of accurate fine detail reproduction with taking into account that different areas may, in general, correspond to the so called line work and continuous tone to various extent and gradually transform in each other in real image. It should be certainly noted that for the sharp transition of a full contrast this system works as well as the screen of the highest of predetermined frequencies, i.e. with that related to structure d of figure 3.

Screening errors correction in the «coarse scan / fine print» reproduction

Effecting the input image data, previously to screening, by the differential procedures, such as provided, for example, by the unsharp masking (USM) operator, doesn't improve the resulting fine detail accuracy. Figure 6c illustrates that in relation to model of figure 6b, both showing the halftone produced with the sampling factor of 1.0 for b/w fragments (figure 6a) of some initial CT image. The latter is taken here as the upper limit for comparison with all the other positions of figure 6. More accurately the characters are looking at fig. 6d where their edges are presented by halftone dots, which are roughly cut along the contours due to the quadruple excess of an input data at a sampling factor of 2.0. It should be noted that the halftone dot formation for images on figure 6b and figure 6d exactly corresponds to one demonstrated for a single screen mesh by models of figure 1c and figure 1f.

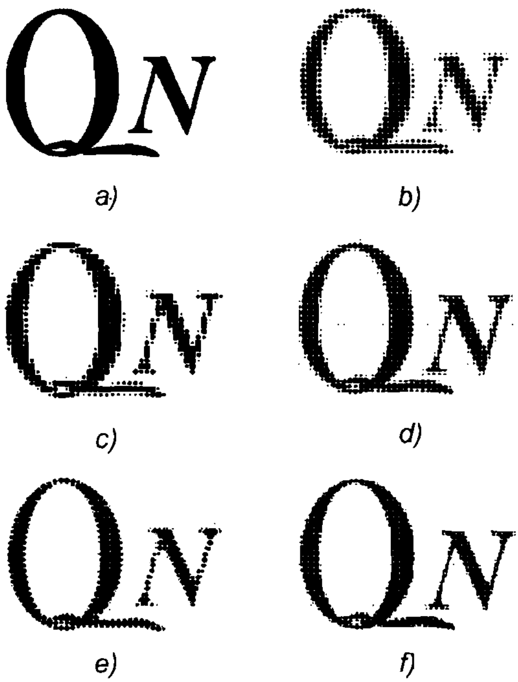


Figure 6. Halftones of details of full contrast (a) at SF values 1.0 (b, c, e), 2.0 (d, f), with USM (c), with dots (e) and their parts (f) displacement

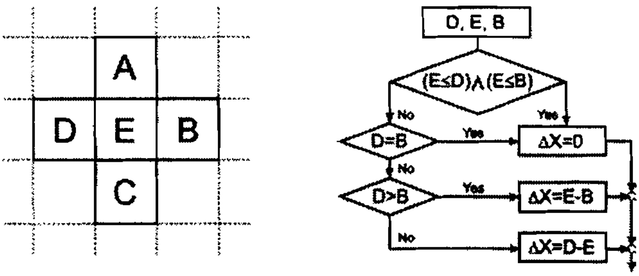


Figure 7. Algorithm of correcting the addresses of microdot weights for halftone dots displacement on contours

Alternatively to input data increasing it was suggested to provide the similar effect by the use of halftone dots which are elongated in direction of a contour (Hammerin, Kruze 1994). In our method (Ershov and others, 1987) such effect has place due to the dots or their parts displacement within the areas of contour transition. Dots are shifted in direction of a darker part of an image intersected by contour and to extent depending on the contour contrast. Direction and degree of displacement is determined by analyze of grey values relationship for the given (E) and adjacent (A-D) sampling areas. This is provided according to algorithm (figure 7a) of correcting the addresses X and Y of microdot weights in screen function periods presented by figure 1a or figure 1b. Decision on the microdot formation is taken by comparison of sampled grey value with a weight which is positioned in screen matrix with displacement ΔX and ΔY to that of the given microdot. Outline of the 50% halftone dot for values $\Delta X = -2$ and $\Delta Y = 1$ is indicated on figure 1a by solid line. The result of this kind of correction can be seen on the enlarged version of the halftone for the light stripe on the black background on figure 8.

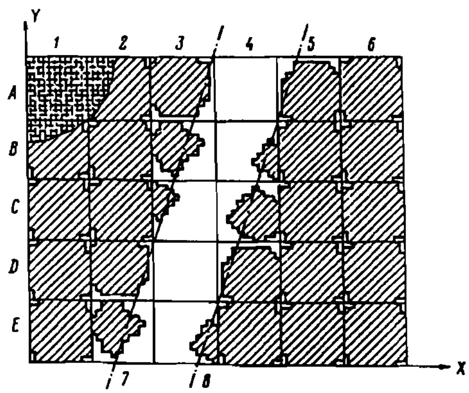


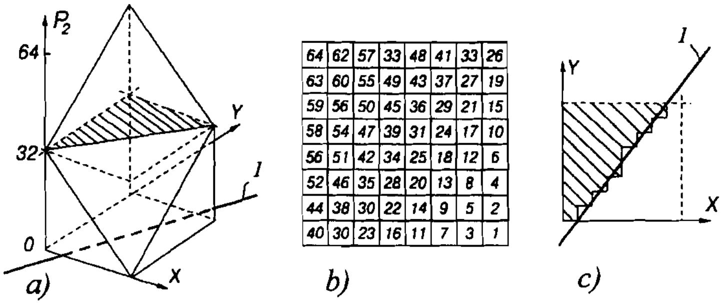
Figure 8. Correcting the contour accuracy by the halftone dots displacement (SF 1.0)

In more realistic scale this effect is illustrated by halftones on figure 6e and figure 6f produced correspondingly with screening factors of 1.0 and 2.0. Characters of figure 6e are looking much better than on figure 6b and are comparable in accuracy with those on figure 6d, in spite of the fact the latter were produced with the use of four times greater volume of an input data. When applied to halftone produced at a screening factor of 2.0, the effect of such differential operator is contrary of unsharp masking one. Instead of destroying contours by the halftone dots, as it is vivid from figure 6c, these dots are subject to fragmentation themselves with their parts adjoining the edges of an image detail. This effect is displayed in the smaller opening of the Q character on figure 6g as further improving its accuracy in relation to model of figure 6d.

Similar approach was successfully used in analogue electronic dot generator of the commercial PDI scanner in 70ties (Moe and others, 1976).

Adaptive screening in a «coarse scan / fine print» system

Minimal spatial discrete unit, which determines contour and fine detail reproduction accuracy in above described methods, is a screen mesh (at SF of 1.0) or its quater (at SF of 2.0) both comprised of plurality of microdots, but not by the microdot itself, whose ultimately determines the resolution of an output device or of a whole printing process. So, it looks quite reasonable to eliminate halftone dots from the sharp transitions while preserving them just for the continual parts of an image. This is performed, for example, by combined use of a trivial screen hill and a supplementary set of matrixes for the microdot weight positions within the sampling area, each positioning relates to certain kind of fine detail geometry (Kuznetsov, 1993). One of such matrixes, intended for inclined contour, and reproduction of the latter within this matrix area are shown on figure 9. It should be noted that contour accuracy, provided here on the basis of a single multi level sample of an input data (at SF of 1.0), is just the same as on figure 1(g, h), where as much as 64 such samples were used at SF of 8.0.



64	62	57	33	48	41	33	26
63	60	55	49	43	37	27	19
59	56	50	45	36	29	21	15
58	54	47	39	31	24	17	10
56	51	42	34	25	18	12	6
52	46	35	28	20	13	8	4
44	38	30	22	14	9	5	2
40	30	23	16	11	7	3	1

Figure 9. Inclined b/w transition 1 reproduced (c) by means of supplementary screen function (a, b) at SF of 1.0

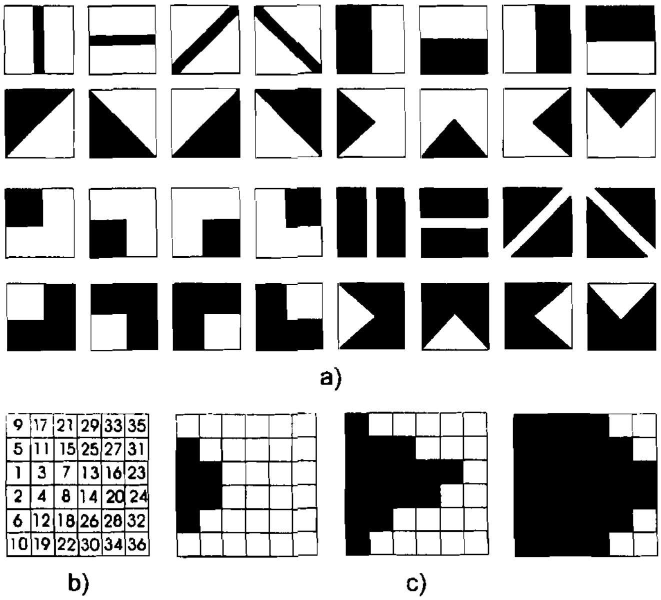


Figure 10. Exemplar types (a) of fine detail geometries to be restored by use of additional screen functions; one of them (b) and its realizations (c) for grey levels of 17%, 50%, 83% (b)

Complementary weight distributions correspond to some additional alphabet of bit-maps for a given grey scale. Alternatively to such distributions, this alphabet can be also determined by some analytical description or by the equivalent set of bit-maps. Method of generating these complementary screen functions can be also different. One of them is comprised in calculating the weights in one step («on fly») from the grey values of neighbouring areas and provides smooth longitudinal rendition of a single contour line (Kuznetsov, 1997). Due to its interpolative nature such kind of approach may, however, be not so effective for thin stripes and individual fragments of sophisticated configuration. Set of complementary screen functions, schematically shown for example on figure 10, can also be given in advance, the required function to be selected on a pattern recognition basis by taking into

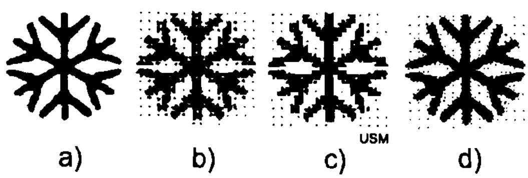


Figure 11. Restoring the coarsely scanned fine detail (a) of sophisticated geometry by basic (b, c), by basic and auxiliary (d) screen functions of figure 10

account grey values of an adjacent areas. With an appropriate identification table for such functions the fine detail of full contrast is restored on the level of printing system resolution (figure 11d) instead of being damaged by the halftone dots (figure 11b, c). Similar approach was suggested for restoring multi level, though coarsely scanned, line work at fine resolution of a facsimile receiver as effective encoding the bi- level image at the very begining input stage (Schatz and Wong, 1977).

Similar to that described above for screen frequency increasing on contours, the basic screen function, intended for the stationary areas, and the supplementary ones, proposed for the sharp transitions, are to be used in certain proportion for contours of an intermediate contrast. To avoid false pattern appearance this proportion should also be changed continuously, when the strength of a contour varies gradually. For this purpose the resulting amount of microdots, which are proposed to be set within a sampling area according its grey level value M, is divided in two parts corresponding to basic and additional screen functions by the following equations:

$$M_1 = M + q(M_{max} - M)$$

$$M_2 = M_{max} - q(M_{max} - M),$$

where M_1 and M_2 are parts of grey value M operating with two kinds of those functions; M_{max} - maximal value for «white» which is equal, for example, to 255th level in quantization scale; q - relative busyness factor. For stationary area, where $q = 0$, $M_1 = M$ and microdots are set dark corresponding to the slice of a screen hill at its Mth level. Supplementary function doesn't partcipate for it is comparated in this case with value M_{max} of white. To the contrary, for b/w fine detail, when $q = 1.0$, $M_2 = M$ and all the nesessary amount of microdots is positioned with accurate matching this detail geometry as predetermined by the corresponding auxilary screen function. Above equations undermine mutual merging of two discussed screening modes by the linear law, which can be modified in favour of one of them depending on the overall content of an image to be reproduced.

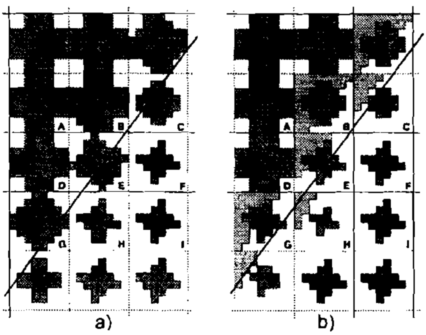


Figure 12. Microdots locations on a "soft" contour according to a single screen hill (a) and in adaptive method (b) at SF of 1.0

Example of sumalteneous use of the both functions is illustrated by figure 12b for the contour of intermediate contrast (q = 0.5) in comparison with trivial reproduction on figure 12a. Microdots, which are formed according to auxilary function, are indicated there lighter than those produced by the screen hill.

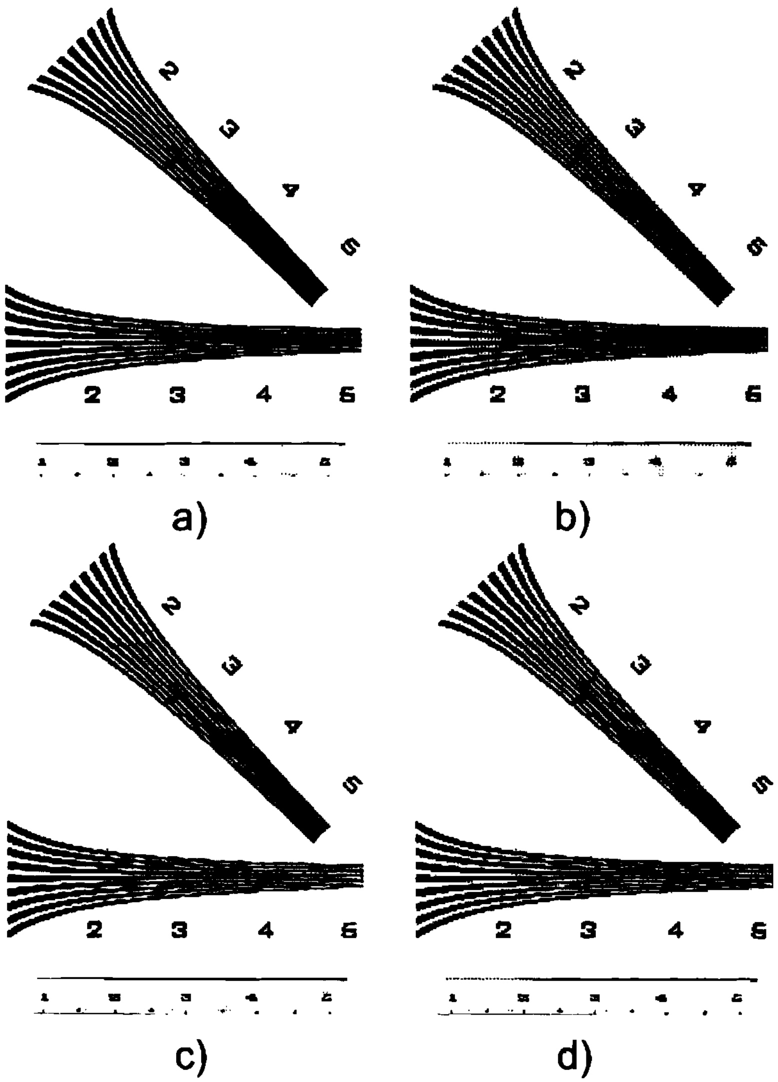


Figure 13. Conventional halftones (b, d) and adaptive sreening (a, c) of a resolution test and an isolated line at SF of 2.0 and 50 Lpi; without (a, b) and after (c, d) USM

Resolution test on figure 13 makes also visible some improvement in definition of halftone print produced by this method as compared with traditional one, even if the latter was supported by some enhancment procedure.

During this method development the special attention was put to the fact that, being non-iterative but parallel, algorithms of adaptive screening, when implemented in a DTP software, as well as, in hardware of RIP or electronic dot generator of output device, should not reduce the speed of their performance.

Figure 14 shows realistic halftones produced by given and trivial screening without USM (Figure 14 a, b) and incorporating it (Figure 14 c, d), all of the images obtained in coarse scan / fine print mode, i.e. at SF of 2.0.

Conclusions

The following can be concluded from foregoing discussion and comparative viewing of prints on figure 14.

Taking into account preferred printability of periodic halftone the improvement of related screening process should not affect dot pattern of a stationary image area, while it's also desired to provide such an improvement without excess of input image data.

In the method described periodically positioned halftone dots, which provide satisfactory tone rendition in continual parts of all images on figure 14, no more exist on contours and fine details of full contrast on prints of figure 14 (a, c). This kind of picture details are «cut out» as accurately as they were at the times of manual engraving.

«Softer» fine details are restored with the partial use of «engraving», degree of the latter adjustable on editor's requirement.

Reproduced at the same density range settings the greater sharpness and definition of print on figure 14 (a) make its appearance higher in luminance contrast than image on figure 14 (b).

Effect of adaptive screening is additive to conventional corrections. When applied to an image file after its unsharp masking, this method restores loss of sharpness and definition involved by a screening process itself: print of figure 14 (c) resolves sharper edges and smaller details of those on figure 14 (d).

Aknowledgements

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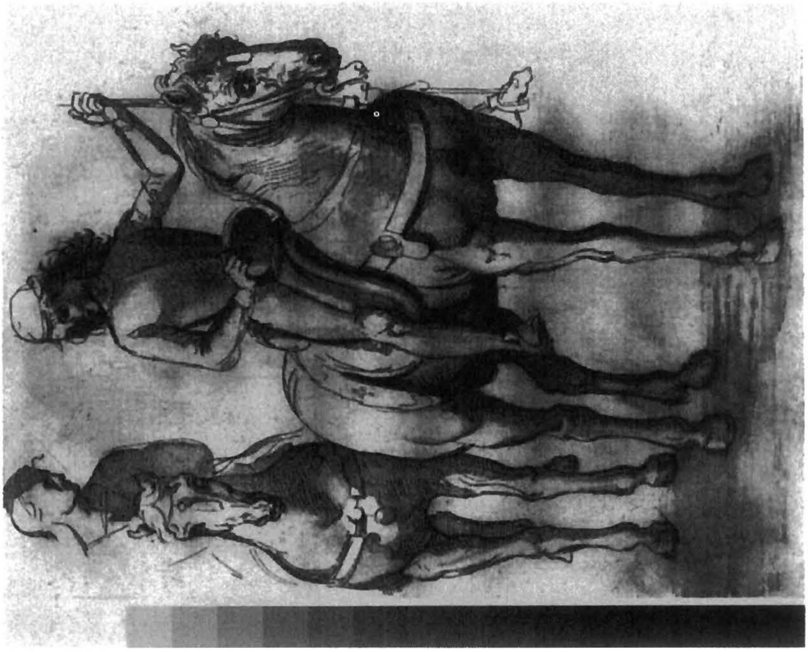

Figure 14 (a). Halftone produced at SF of 2.0 by adaptive screening.

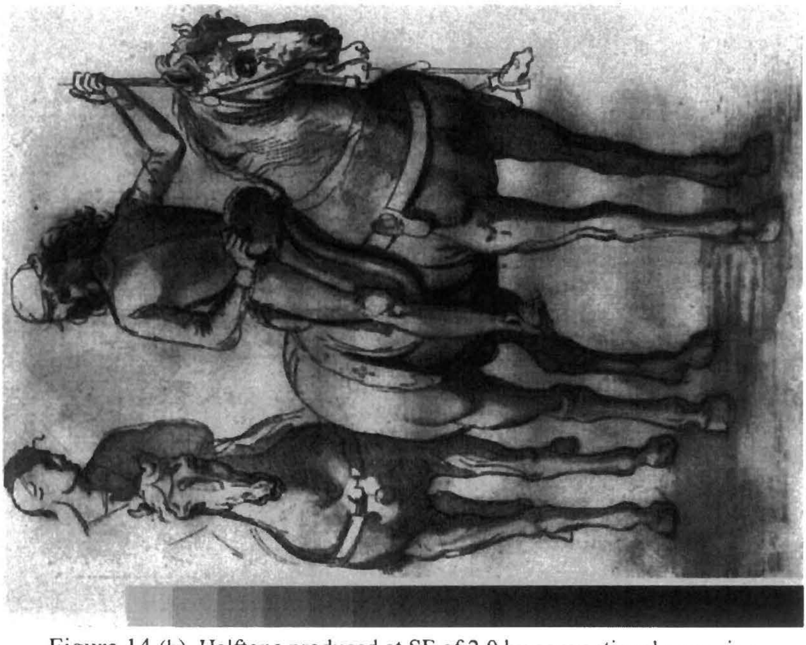

Figure 14 (b) Halftone produced at SF of 2.0 by conventional screening.

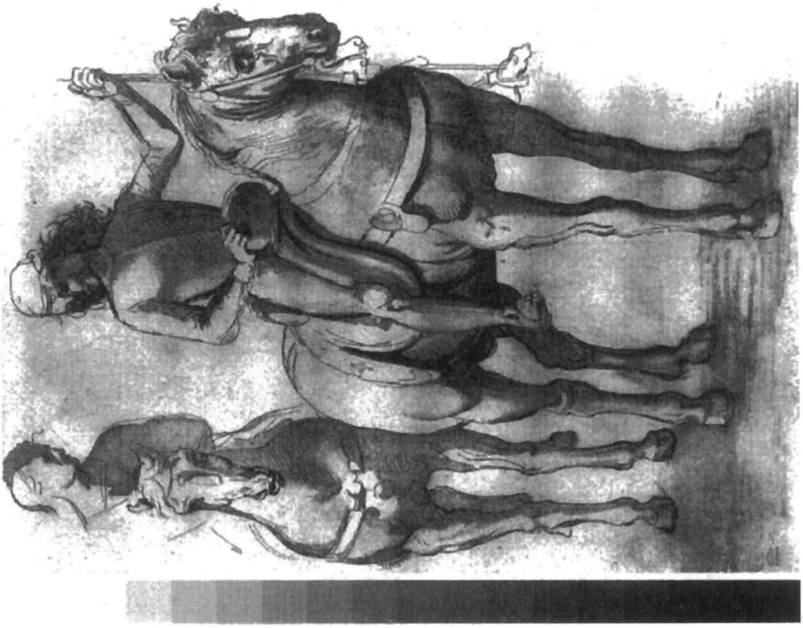

Figure 14 (c) Halftone produced at SF of 2.0 by conventional screening after USM.

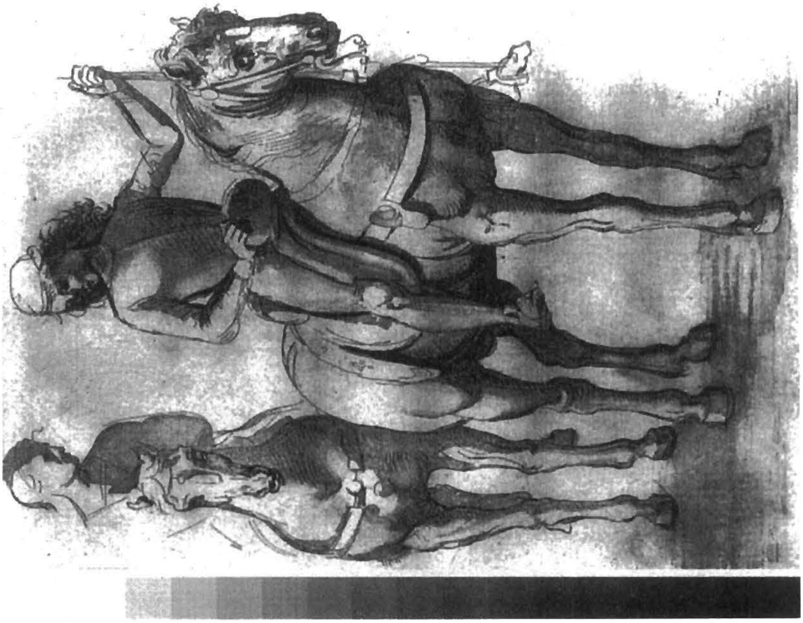

Figure 14 (d) Halftone(b, d) produced at SF of 2.0 by adaptive screening after USM.

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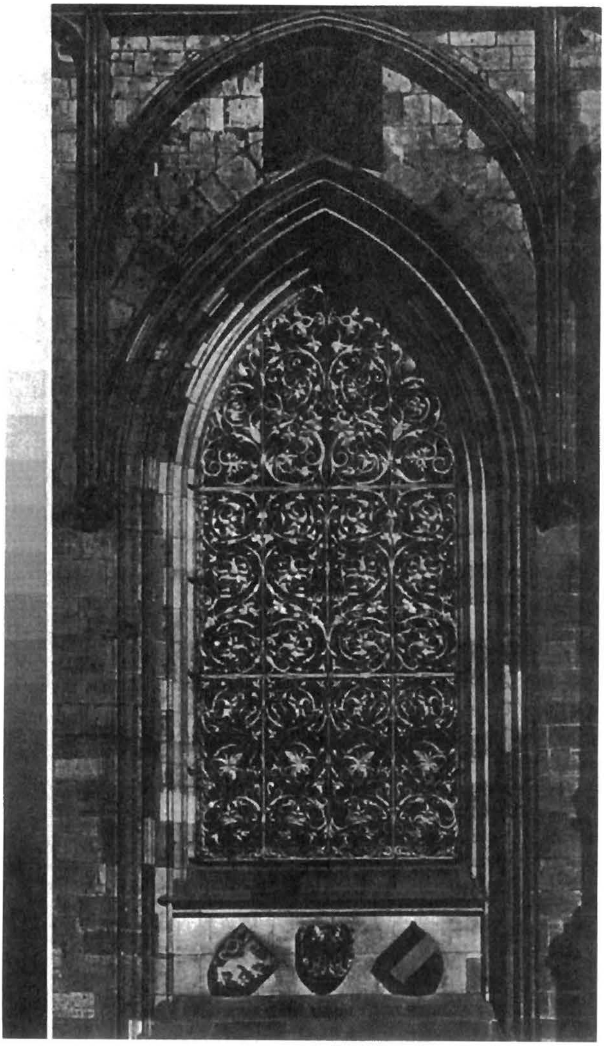
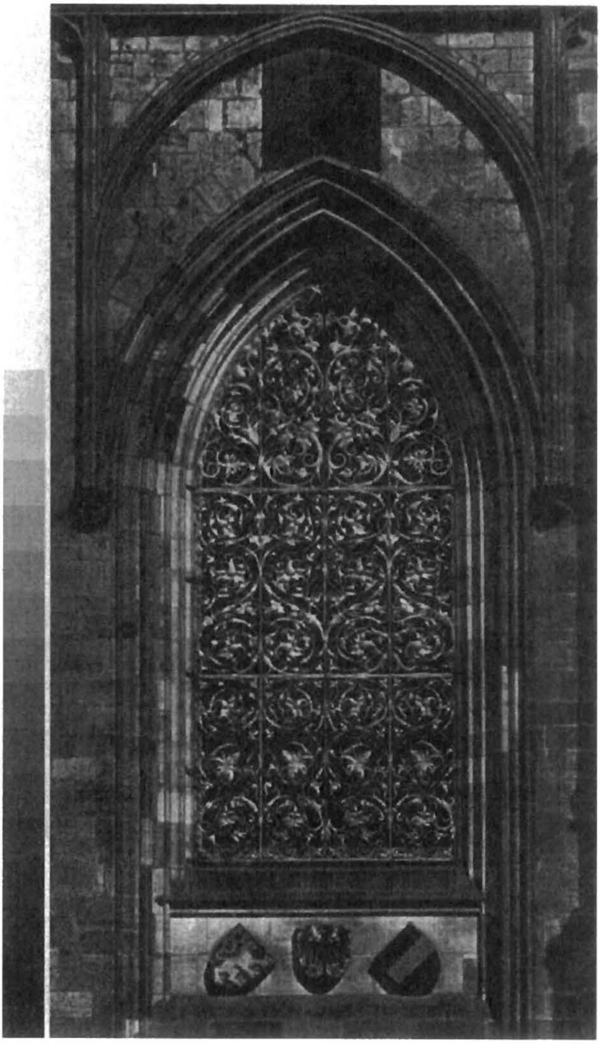


Appendix A (1). Halftone produced at SF of 2.0 by adaptive screening.



Appendix A (2). Halftone produced at SF of 2.0 by conventional screening.

Appendix B (1). Halftone produced at SF of 2.0 by adaptive screening.

Appendix B (2). Halftone produced at SF of 2.0 by conventional screening.