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Displaying Halftone Pictures on a Dot Plotting Device

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Abstract

A new method for displaying halftone pictures using a dot plotting device is given. The method gives a good result, especially when the cell size is small. The problem of reducing the cell size is also treated.

1. INTRODUCTION

Displaying halftone pictures using binary output devices is an improtant function in picture processing systems, because they usually work rapidly and leave hardcopies. Especially dot plotting devices are recently come into wide use and have some merits in contrast to character printing devices; the cell size is relatively flexible, the gap between cells are invisible and so on.

The following is the most primitive method of displaying halftone pictures by dot plotting devices. For the sake of convenience, we will say that input brightness values are between zero and one.

First we assign a square array of NxN dots, called a cell, to each point of an input picture. Next we multiply the input brightness by N^2 and quantize it into the nearest integer, m. Finally, from a prepared set of NxN dot patterns, we choose a pattern of m white dots and fill the cell with it.

This method will show two defects. One is contours due to the quantization and the other is moire patterns formed by repeated placements of the same pattern. To remove these defects, some improvements are already proposed; addition of noise before quantization or design of less objectionable binary patterns [1].

In section 2, we give a new method based on randomized decisions. In section 3, the relation of the cell size to the spatial and brightness resolutions are treated.

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2. PROBABILISTIC DISPLAY METHODS

In this section two display methods are given. The former is not a new one, but is given for the comparison. The latter, an improvement of the former, gives a satisfactory result.

Let B be the input brightness value between zero and one. Let R(i,j) be the value of a dot at (i,j) position of the cell of NxN dots. R(i,j)=1 or R(i,j)=0 mean that the dot is white or black respectively.

Then S, the output brightness, is given by

$$S=\sum_{i=1}^{N}\sum_{j=1}^{N} R(i,j)/N^2$$

and can take the N^2+1 values of 0, $1/N^2$, $2/N^2$,...., 1.

For example, by the primitive method in the previous section,

$S=m/N^2=[N^2B+1/2]/N^2$ ([y] is the gretest integer not greater than y.)

and

R(i,j)=Gm(i,j)

where Gm is a NxN binary pattern and $\sum_{i=1}^{N}\sum_{j=1}^{N} Gm(i,j)=m$.

2.1 INDEPENDENT PROBABILITY METHOD

This method sets each dot white with the probability proportional to the brightness. This is done as follows.

For each dot (i,j), generate a random variable, r, uniformly distributed between zero and one. If $r<B$ then set $R(i,j)\leftarrow 1$, else set $R(i,j)\leftarrow 0$.

By this method, the number of white dots in a cell has the binomial distribution (N^2,B), so the expected value of the brightness is equal to the input brightness, B. However, because of the property of the binomial distribution, the number of white dots can take many values, sometimes far from the nearest integer. This leads to great noise on the displayed picture.

2.2 CONDITIONAL PROBABILITY METHOD

This method also set each dot white or black by randomized decisions. The difference from the previous method is that the probabilties varies as a function of the previous decisions, so as to decrese the variance of the output values.

S1. [Initialization] Set $a \leftarrow N^2$ and $b \leftarrow N^2B$. (a and b mean the number of undecided dots and the white dots to be appeared hereafter. Notice that b is not restricted to integers.)

S2. [Pick up a next point] Pick up a undecided dot in the cell and let (i,j) be the position of the dot in the cell.

S3. [Branch] Generate a random variable, r, uniformly distributed between zero and one. If $r<b/a$ go to step S4, else go to step S5.

S4. [A white dot] Set $R(i,j) \leftarrow 1$ and $b \leftarrow b-1$. Go to step S6

S5. [A black dot] Set $R(i,j) \leftarrow 0$. Go to step S6.

S6. [Termination test] Decrease a by 1. If a=0 then the algorithm terminates, else return to step S2.

When the value N^2B is equal to some integer, this method give the results that $Prob(R(i,j)=1)=B$ for all (i,j) and S=B.

For the general value of B, these results are not brought. However, S takes only two values of $[N^2B]/N^2$ and $[N^2B+1]/N^2$ as follows. If $[N^2B+1]$ dots are set white during the execution of the algorithm, then b becomes negative and the remaining dots are set black; the result is $S=[N^2B+1]/N^2$. If $N^2-[N^2B]$ dots are set black, then a becomes less than b and the remaining dots are set white; the result is $S=[N^2B]/N^2$.

Fig.1 and Fig.2 show the difference between the two probability methods. In each graph, we plot the average of the output of a cell as a function of the input value. Fig.1 illustrates that by the independent probability method the average becomes exactly equal to the input, though the variance is large. Fig.2 illustrates that the variance is small, though the average is slightly different from the input.

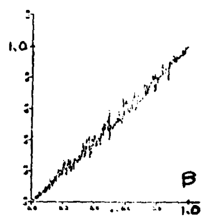

Fig.1

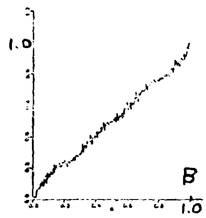

Fig.2

2.3 EXPERIMENTAL RESULTS

Fig.3, Fig.4 and Fig.5 are examples of the output pictures by the primitive method, the independent probability method and the conditional probability method respectively. Each picture consists of 256x256 cells and the cell size is 2x2. The input picture is digitized from a photograph with a DICOMED D57 Image Digitizer. The outputs are displayed on a TEKTRONIX 611 storage tube display and photographed.


Fig.3


Fig.4


Fig.5

In Fig.3, by the primitive methods, the quantizing contours are apparent. In this example the number of dots in a cell is so small that the moire pattern is not obvious. However, specific textures of fine vertical lines are dominant.

There are no quantizing contours in Fig.4 and Fig.5 and the textures are randomized. Fig.5 is finer and smoother than Fig.4, because the variance of output is smaller as described above.

In displaying Fig.4 and Fig.5, we intentionally used a pseudo random number generator of low quality, so in Fig.4 some moire patterns are observed but in Fig.5 they are not obvious.

3. REDUCING THE CELL SIZE

The determination of the number of dots in a cell, the cell size, is a complex problem. There is usually a trade-off between the spatial and brightness resolutions due to the limited number of dots allowed. In this section we give an example of the trade-off and introduce a technique to reduce the cell size.

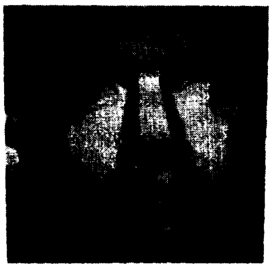
Fig.6


Fig.7


Fig.8

The picture in Fig.6 is displayed by the conditional probability method using 2x2 dots per a cell. Fig.7 is also displayed by the same method but using 4x4 dots per a cell and a value for a cell is sampled from 2x2 data of the input. Fig.8 is displayed by the same way using 8x8 dots per a cell. These examples suggest that the cell size of 2x2 is adequate for high-detailed or sharp-edged pictures.

In the area of pictorial data transmission, the improved gray scale technique is one of the most successful ones [2]. The main principle of this technique is to carry the difference between the input and the output to the next neighboring cell. Fig.9 shows the result by the primitive method coupled with this technique.

Fig.9

Fig.10

Comparing Fig.9 to Fig.3, we can observe a great improvement of the picture quality, though fine ripples are remaining. Fig.10 is displayed by the conditional probability method coupled with the improved gray scale technique, using only one dot per a cell. There are slight ripples but the picture quality is very good for such a small cell size.

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