Evaluation of Graininess for Digital Halftone Images Based on Human Visual Sensitivity

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Abstract

In this paper we show some results of image recognition tests in which a testee looks at an image and tell if he/she can recognize a certain figure in it or not. When we study digital halftoning process, it is important to discuss the resolution of the human eye, or eye and brain, from the viewpoint of image recognition.

Introduction

Algorithms of converting a continuous-tone image into a binary high quality image are important in non-impact printing field. A great number of digital halftoning algorithms have been presented. Recently, FM screening has been extensively studied. In 1998 and 1999 we discussed the relationship between the minimum dot size and the print quality considering the human visual sensitivity. Through these results we recognized the importance of halftone screening method, which is one of the most widely-used binarization methods in printing and publishing industry. In 2000 and 2001 we discussed the stability of the shape of minimum dots and the merits of clustered dots. We presented many experimental results and their analyses with respect to the relationship between the size and the stability of clusters in 2002 and 2003.

In this paper we compare several binarized images and disuss the resolution of the human eye, or eye and brain, from the viewpoint of image recognition. The resolution of the human eye has been studied for a long time and many numbers are determined since 1897 under various conditions. Our results will lead to the answer for the following question; how high the frequency is for an image below that we recognize high graininess?

In the follwing, we describe a basis of ordered dither method which we used in our experiment. Then we show the result of our experiment and discuss it. Finally we summarize the discussion.

Clustered-Dot Ordered Dither

Ordered dithering techniques can be divided into two classes by the nature of the dots, or clusters of dots, produced, clustered and dispersed. In this paper we use clustered-dot dither because it is the most widely used hafltoning technique in the printing process.

Clustered-dot ordered dither method can be characterized by the following four aspects; screen angle, screen frequency, dot pattern, level assignment. The original image is divided into cells. Each cell we used has 16 x 16 vertical and horizontal pixels, thus the screen angle is 0°. We denote each cell $A[i, j]$, where a pixel $A[i, j]$ has an integer value I in the interval [0, 255]. We prepare another 16 x 16 dither matrix $B[i, j]$, whose dot pattern is shown in Fig. 1. This is a kind of threshold matrix and each will be compared with repeatedly to generate an output binarized image.

There is a trade-off between the reproductivity of gray-levels and that of spatial resolution. It is said in general that the optimal size of halftone cell is around 4 x 4. However, we used 16 x 16 matrix B because we need to reproduce 256 gray-levels.

0	8	20	39	47	55	63	71	67	59	51	43	35	23	11	3
4	12	31	79	87	95	127	135	131	123	99	91	83	27	15	7
16	24	72	104	116	139	159	167	163	155	143	119	107	75	30	19
32	80	100	108	144	171	187	195	191	183	175	151	111	103	86	38
40	88	112	145	176	199	207	223	219	211	203	179	150	115	90	46
48	96	140	172	200	212	231	239	235	227	215	198	170	138	94	54
56	120	152	180	208	224	247	242	244	251	230	206	186	158	126	62
64	128	160	188	216	232	250	255	253	246	238	222	194	166	134	70
68	132	164	192	220	236	243	252	254	245	234	218	190	162	130	66
60	124	156	184	204	228	248	241	240	249	226	210	182	154	122	58
52	92	136	168	196	213	225	233	237	229	214	202	174	142	98	50
44	84	113	146	177	201	209	217	221	205	197	178	149	114	82	42
36	76	101	109	147	173	181	189	193	185	169	148	110	102	78	34
17	25	73	105	117	141	153	161	165	157	137	118	106	74	29	18
5	13	28	77	81	97	121	129	133	125	93	89	85	26	14	6
1	9	21	33	41	49	57	65	69	61	53	45	37	22	10	2

Figure 1. Dither Matrix B

Experimental

First we prepare 6 patterns of sample images BC1, SC1, BT1, ST1, BS1, and SS1, representing Big Circle, Small Circle, Big Triangle, Small Triangle, Big Square, and Small

Square, respectively. '1' of every image name represents the difference of the brightness value from the background. 'BC1', for example is an image of a circle with a diameter of 15 cm and with brightness value of 64, aligned in the center of a square with sides 18 cm and with brightness value of 63, 'SC1' is an image of a circle with a diameter of 6 cm and brightness value of 64, aligned in the center of a square with sides 18 cm and with brightness value of 63, and so on. The resolution of every image is 400 dpi.

Second we change the brightness value of each figure and get BC2, BC3, ..., BC10, SC2, SC3, ..., SC10, ..., SS2, ..., SS10, thus SS10 is a 6 cm x 6 cm square with brightness value 73 aligned in the center of a 18 cm x 18 cm square with brightness value of 63, as in Fig. 2.

Third we binarize each of above 60 original images in three different manners; (1) an original image is divided into cells of 16 x 16 pixels and our dither matrix *B* is applied to determine the output values, (2) an original image is divided into cells of 32 x 32 pixels and for each cell brightness values of 2 x 2 = 4 pixels are averaged and then our dither matrix *B* is applied to determine the output values, where the same output value, 0 or 255, is assigned to these 4 pixels, (3) an original image is divided into cells of 80 x 80 pixels and for each cell brightness values of 5 x 5 = 25 pixels are averaged and then our dither matrix *B* is applied to determine the output values, where the same output value, 0 or 255, is assigned to these 25 pixels. We show three binarized images of SS10 in Fig. 3(1), (2), (3), respectively. Note that binarized images consist of many clustered dots and its frequency is about (1) 1 dot/mm, (2) 0.5 dot/mm, and (3) 0.2 dot/mm, respectively. Thus we get 180 sample images after all.

Figure 2. Original image SS10

Fourth we print the sample digital images on plain papers by using an inkjet printer with maximum resolution 600 dpi which are widely used for personal usage. After that we start the test for human recognition of a figure in gray background. A testee looks at each printed image and tell whether he/she can recognize a figure in it or not. Repeat these process at a distance of 0.5 m, 1 m, 2 m, and 5 m, respectively.

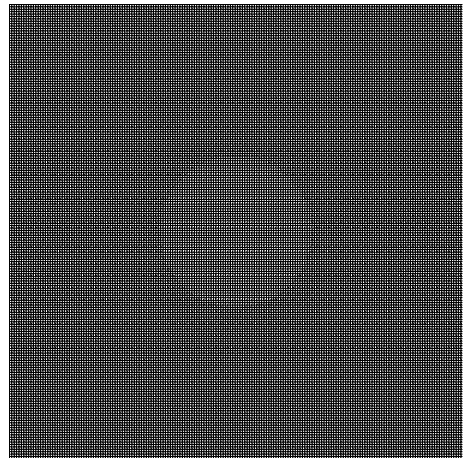

Figure 3(1). Binarized image of SS10 with frequency 1 dot/mm

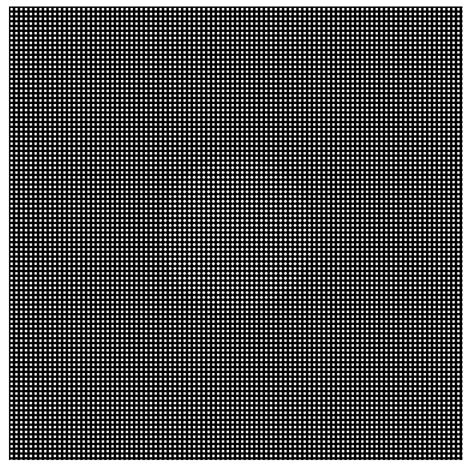

Figure 3(2). Binarized image of SS10 with frequency 0.5 dot/mm

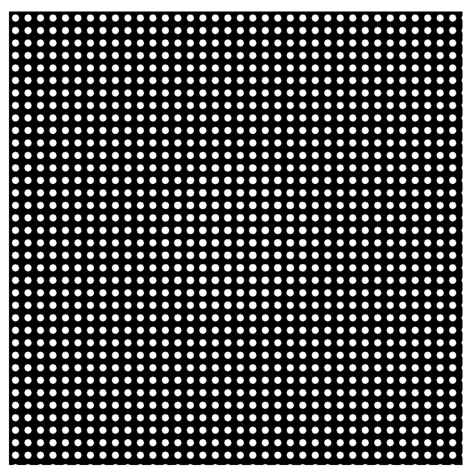

Figure 3(3). Binarized image of SS10 with frequency 0.2 dot/mm

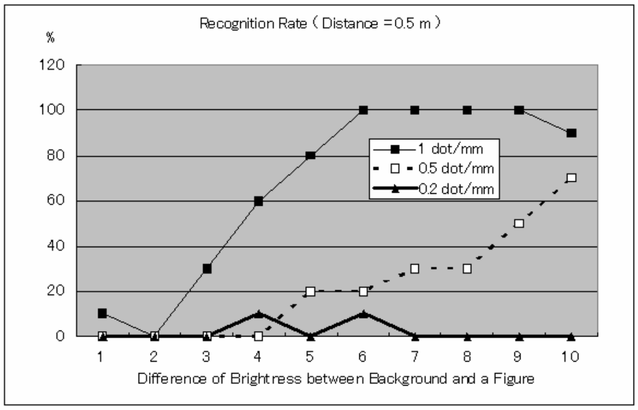

Figure 4(a). Recoginition rate of a small circle at the distance of 0.5 m

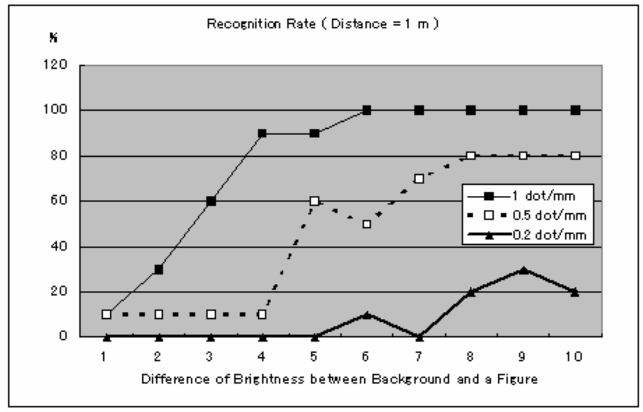

Figure 4(b). Recoginition rate of a small circle at the distance of 1.0 m

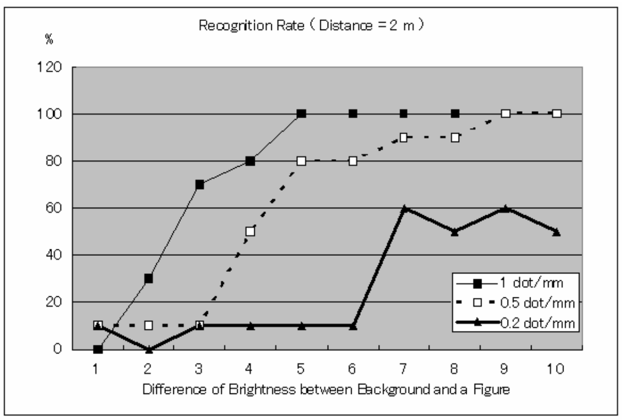

Figure 4(c). Recoginition rate of a small circle at the distance of 2.0 m

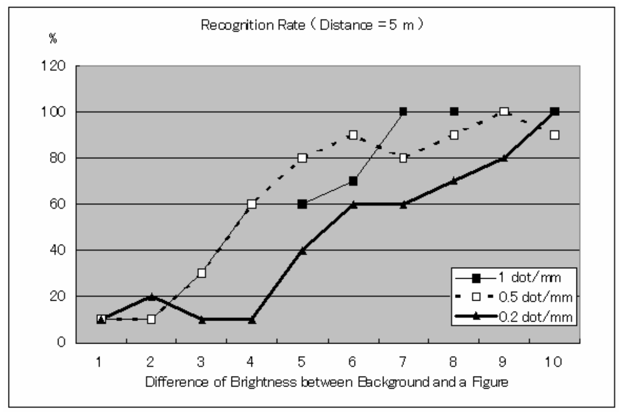

Figure 4(d). Recoginition rate of a small circle at the distance of 5.0 m

Results

The results for ten testees are shown in Figs. 4(a)-(d).

Discussion

From the result the recognition rate is highest in the case of 1 dot/mm. We can say the recognition rate gets higher as the frequency of clustered dots gets higher. This is because most of the testees perceive the shape of the figure as a whole. In other words, they perceive not each clustered dot but a cluster of clustered dots.

In the case of lower frequency people perceive the graininess of each clustered dots because they can clearly see white area around each clustered dot.

In the case of 0.2 dot/mm, the recognition rate gets higher as the distance between the testee and the image gets longer. This result can be explained in the same manner as above.

As for the difference of brightness value between the figure's and background's, recognition rate gets higher as the difference gets bigger, which is predictable. We can say, however, there is a certain value of difference at that the recognition rate changes radically. For example, in Fig. 4(d) the average recognition rate raises from 37% to 60% when the difference of brightness value increases from 4 to 5. It is expected that there exists a critical value of brightness which sharply stimulates human visual sensitivity.

As future works, the following items will be remained;

1. characterize the relationship between the recognition rate and the angle of vision; the angle depends on the fixation point,
2. consider the influence of light level, and
3. consider the eyesight of each testee.

Conclusion

We made 180 different binarized images with different spatial frequency. We then did some tests using them in order to find the critical point where our attention is attracted more to the image as a whole than to the dots. From the result, 5 seems to be a big difference of brightness value when we see a 256 continuous tone image.

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Biography

Kitakubo Shigeru is Assistant Professor of Nippon Institute of Technology. He received his B.S., M.S. and Dr. degrees in Science from Tokyo Institute of Technology in 1986, 1988, and 1992, respectively. Since 1993 he has worked in Nippon Institute of Technology. His work has primarily focused on digital processing theory, including halftoning technique and image quality issues. He participates in NIP conference every year since 1995.