RELATIONSHIP BETWEEN ERROR DIFFUSION COEFFICIENTS, OBJECT SIZE AND OBJECT POSITION FOR CGH

Susumu Nishi and Ken-ichi Tanaka

Department of Electronics and Bioinformatics, School of Science and Technology
Meiji University
1-1-1 Higashi-Mita, Tama, Kawasaki, 214-8571, Japan
E-mail: { ce77067, Tanaken }@ise.meiji.ac.jp

ABSTRACT

Computer-Generated Hologram (CGH) is made for three dimensional image of a virtual object. Error diffusion method is used for the phase quantization of CGH, and it is known to be effective to the image quality improvement of the reconstructed image. However, the image quality of the reconstructed image from the CGH using error diffusion method depends on the selection of error diffusion coefficient. In this paper, we derived the relational expression to obtain the error diffusion coefficient from the position of the input object and size of the input object for CGH. As a result, the method of this thesis was able to obtain an excellent reconstructed image compared with the case to derive the error diffusion coefficient from only the position of the input image.

Keywords: Computer-generated Holograms, Error Diffusion Method, Diffusion Coefficient, Optimization

1. INTRODUCTION

CGH are fabricated for reconstruction virtual 3D (Three-Dimension) object that difficult to illuminate laser light directly. However, it is necessary to obtain the reconstructed image with a good image quality in as easy a computational method as possible.

In the fabricating process of CGH[1]～[3], one of the factors for it to have a big influence on the image quality of the reconstructed image is a quantization of the wave front. Error diffusion method is used for the phase quantization of the CGH. The reconstructed object and the noise can be separated by Error Diffusion Method[1]～[4]. However, the selection of diffusion coefficient exerts an influence to the image quality of the reconstructed image. Error-diffusion method is expected to fast generation for CGH's that can obtain the image of the high-resolution, compared with optimization algorithms.

By the way, previous article investigated the optimal selection of the error diffusion coefficient using modern heuristic techniques such as Genetic Algorithm (GA)[9] and Simultaneous Perturbation Algorithm (SPA)[10]. This author's group found the relation between the position of the object and the error diffusion coefficients for CGH's. However, the size of the object is not considered in this method. It is probable that the diffusion coefficients depend on the object size.

This paper introduces the estimation of error-diffusion coefficients for CGH using statistical analysis consider the object position and the object size.

2. METHOD

This section describes the method of making CGH by the Error diffusion method.

2.1 Making of CGH by error diffusion method

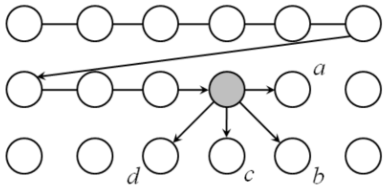
This section describes the method of a numeric synthesis of Fourier transform type CGH. The discrete coordinate system on the original picture image side is defined as point(x, y). And, the discrete coordinate system on the Fourier transform side is defined as point(u, v). Random phase $\emptyset_R$ is multiplied by input image$f(m, n)$. It stores in the memory of the computer. This random phase is a uniform random number distributed from 0 to 2π, and has working that thoroughly distributes the spectrum. According to the next expression, the Discrete Fourier transform of this input image$f(m, n)$ is marked, and it finds for a Fourier transform image.

$$F(u,v) = \frac{1}{\sqrt{N^2}} \sum_{m=0}^{N-1} \sum_{n=0}^{N-1} f(m,n) \cdot \exp\left\{ -j \frac{2\pi(mu+nv)}{N} \right\} \quad (1)$$

However, N is a number of pixels for one side in the original picture image plane, and N=128 in this research. This $F(u, v)$ is made a phase quantum by using the random dither. CGH is made by displaying black and white and binary.

2.1 Phase quantization that uses error diffusion method

This section describes the phase quantization by Error Diffusion Method. First of all, the Fourier transform image point $F(u, v)$ is scaling so that the maximum of the absolute value of a real part in the complex value may become one. And, it makes to the phase quantum it in binary as for scaled value $F(u, v)$. However, the phase quantization begins from point(u,v)=(0,0), and the



$$|a|+|b|+|c|+|d|=1$$

Fig.1: Diffusion Coefficient.

algorithm in coordinates point(u,v) is generally as follows by the raster scanning.

$$F'(u,v)\begin{cases}+1 & (\pi/2 \leq |arg[F_s(0,0)]|) \\ -1 & (otherwise)\end{cases} \tag{2}$$

$$s(u,v) = F_s(u,v) - F'(u,v) \tag{3}$$

$$F_s(u+1,v) = F_s(u+1,v) + a \times s(u,v) \tag{4}$$

$$F_s(u+1,v+1) = F_s(u+1,v+1) + b \times s(u,v) \tag{5}$$

$$F_s(u,v+1) = F_s(u,v+1) + c \times s(u,v) \tag{6}$$

$$F_s(u-1,v+1) = F_s(u-1,v+1) + d \times s(u,v) \tag{7}$$

Here, $s(u,v)$ is a quantization error, and this to Fig.1 Error diffusion coefficient a〜d is multiplied and it diffuses to a surrounding pixel as being. However, the error margin diffusion to the area where point (u,v) is not defined is not done. Moreover, expression (7)〜(3) means the one of the seen form, and the left side substitution again of a right value for the procedural computer language.

From the above mentioned procedure, the hologram is made by displaying the result of making it to the quantum in binary.

3. DERIVATION OF THE POSITION AND SIZE OF OBJECT AND A RELATION WITH DIFFUSION COEFFICIENT

This chapter describes the technique of choosing an error diffusion method from position and size of the object.

3.1 Collection of optimal error diffusion coefficient data

The object used for collection of data by this research is a thing of Fig. 2 (a), and Fig. 2 (b) is the example of arrangement. The size of an original image is set to N, and the size of an input object uses the object of the square of 32×32 (L= 32) from 8×8 (L= 8). The gradation concentration of this square domain is considered to be a fixed thing. The position of input object is moved every 1 pixels in side in length, and the error margin diffusion coefficients optimized by GA at each position are collected. In this case, the evaluation value used with GA uses mean square error E that shows the error margin of the original picture image and the reconstructed image. If the value of E is smaller, the image quality is well. Moreover, the calculation of E was assumed to be the one according to next expression[7].

$$E = \alpha_1 E_1 + \alpha_2 E_2 \tag{8}$$

$$E_1 = \left\langle \left| |g|^2 - \frac{\langle |g| \rangle^2}{\langle |\gamma| \rangle^2} |\gamma|^2 \right|^2 \right\rangle \tag{9}$$

$$E_2 = \left\langle \left| \frac{|g| - \langle |g| \rangle}{\sigma_{|g|}} - \frac{|\gamma| - \langle |\gamma| \rangle}{\sigma_{|\gamma|}} \right|^2 \right\rangle \tag{10}$$

Here, $|g|$ is amplitude of the original image, $|\gamma|$ is amplitude reconstructed, $\langle\cdot\rangle$ is mean of $|\cdot|$, and σ is standard deviation concerning the affixing character. About this cost function, E_1 contributes to the contrast of the image, and E_2 contributes to the difference of the amplitude of the image. In this research, the image is evaluated by $\alpha_1 = \alpha_2 = 0.5$.

3.2 Approximation to the optimal error diffusion coefficient by multiple linear regression analysis

Here, the optimization shown in the preceding chapter searches for an error diffusion coefficient, and the result is accumulated as data. Although the foregoing paragraph showed the position(x,y) of an input object, and size l of an input object and combination with the diffusion coefficient a~d, an expression of relations is derived about this. In deriving this expression of relations, it thinks as Mth following polynomials, and it finds for the coefficient in the expression in approximation. However, this expression (14)〜(11) shall have the following restrictions.

$$a = \sum_{i=0}^{M}\sum_{j=0}^{M}\sum_{k=0}^{M} a_{ijk} x^i y^j l^k \tag{11}$$

$$b = \sum_{i=0}^{M}\sum_{j=0}^{M}\sum_{k=0}^{M} b_{ijk} x^i y^j l^k \tag{12}$$

$$c = \sum_{i=0}^{M}\sum_{j=0}^{M}\sum_{k=0}^{M} c_{ijk} x^i y^j l^k \tag{13}$$

$$d = \sum_{i=0}^{M}\sum_{j=0}^{M}\sum_{k=0}^{M} d_{ijk} x^i y^j l^k \tag{14}$$

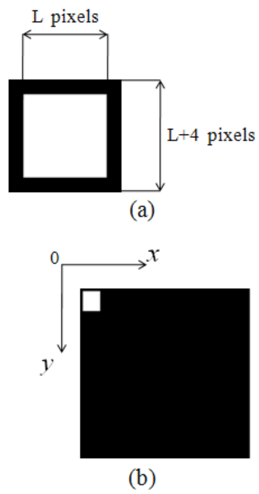


Fig.2: Input Object and Sample Images.

Table.1: Polynomial coefficients (2nd)

Subscript ijk	aijk	bijk	cijk	dijk
000	0.4514027	0.0396752	0.4746034	0.0707078
100	0.0700189	0.0135677	-0.001017	-0.01268
010	0.0087924	0.0141373	0.0682287	-0.001039
001	-0.009727	0.009861	0.0162539	0.0045899
110	0.0216247	-3.158881	0.1563652	2.848377
101	0.0143962	0.0328508	0.0175834	-0.003671
011	-0.002997	0.0398027	0.0175466	-0.015782
200	-5.476952	-0.234962	-0.183366	-0.453046
020	-0.056584	-0.20974	-5.607989	-0.383423
002	-0.119507	-0.121087	-0.232336	-0.17042

Table.2: Polynomial coefficients (3rd)

Subscript ijk	aijk	bijk	cijk	dijk
000	0.4524749	0.0452031	0.4807689	0.0788005
100	-0.008792	0.0069185	0.0125004	-0.003026
010	0.0063452	0.0955775	0.1329594	-0.003227
001	0.1441219	-0.005926	0.1215725	0.0044288
110	0.0246177	-3.109553	0.1576174	2.7968743
101	0.000878	0.0013203	0.0127107	-0.007029
011	0.010281	-0.025419	-0.038435	-0.018536
200	-5.442986	-0.233214	-0.209629	-0.453577
020	-0.08584	-0.21086	-5.577432	-0.381302
002	-0.244383	-0.319362	-0.52118	-0.473329
210	-0.251796	-0.920032	0.0735605	0.1900167
201	-2.93098	-0.243173	0.364944	-0.352767
120	0.420718	-0.638046	-0.196698	0.0922719
102	0.2712509	0.1816669	-0.01141	-0.014755
021	0.4242827	-0.090944	-2.650602	-0.493531
012	-0.076289	0.0127385	0.0999878	0.0346555
111	-0.157763	-2.600083	-0.066003	2.7146943
300	0.2297854	0.2308785	-0.002005	-0.08967
030	0.1976466	-0.192777	-0.648436	-0.103899
003	0.1608688	0.5478911	0.6538561	0.8100819

$$i + j + k \leq M \tag{15}$$

Moreover, x and y used as the main coordinates of an input object shall take the value of the range of -1/2 ～ 1/2 respectively. That is, even if the number of pixels of a CGH changes, it is for having generality. Here, the CGH of $N \times N$ pixel is assumed. Here, x is taken as the position of the center-of-gravity pixel of the direction of a horizontal axis of an input object, y is taken as the position of the center-of-gravity pixel of the direction of a vertical axis of an input object, and the size of an input object is $L \times L$ pixel. The size which the main coordinates (x, y) of an input object and an input object normalized is called for as follows.

$$x = \frac{i - N/2}{N} \tag{16}$$

$$y = \frac{j - N/2}{N} \tag{17}$$

$$l = \frac{L - N/8}{N/4} \tag{18}$$

However, L shall be $N/8 \leq L \leq N/4$ which is a suitable size in the CGH is which use the error diffusion method. When determining the coefficient a_{ijk}, b_{ijk}, c_{ijk} and d_{ijk} (i, j and k are integers) in expression (14)～(11), Much combination of x, y, l, a, b, c, and d shall be prepared, and least mean square approximation shall perform. Based on the error diffusion coefficient obtained by this optimization, it shall find for the coefficient (a_{ijk}, b_{ijk}, c_{ijk}, d_{ijk}, $i, j, k = 0,1, \ldots M$) of expression (14)～(11) by least mean square approximation.

4. RESULTS

As for the polynomial in the preceding section, a polynomial is connected infinitely. Here, approximation divided into the limited degree shall be performed. This approximation performs four kinds from 2nd approximation to the 5th approximation, and each is shown for that result in Table 4 from Table 1. The subscript k in the inside of table is k by a_{ijk}, b_{ijk}, c_{ijk} and d_{ijk} ($i, j, k = 0,1, \ldots M$). Here, each line in Table 4 is explained from Table 1. 1 column is a subscript which a polynomial attaches, and 2 columns is a value of a_{ijk}. For example, if it is i=1, j=2 and k=3, a_{ijk} means the value of a_{123}. Similarly, 3 columns mean the value of b_{ijk}, 4 columns mean the value of c_{ijk} and 5 columns mean the value of d_{ijk}. It turns out that the polynomial coefficient a_{ijk}, b_{ijk}, c_{ijk} and d_{ijk} ($i, j, k = 0,1, \ldots M$) becomes a value which changes with approximate degrees. By the way, it is considered how the diffusion coefficient

Table.3: Polynomial coefficients (4th)

Subscript ijk	aijk	bijk	cijk	dijk
000	0.5664026	0.1617962	0.6277256	0.2918254
100	-0.008831	0.0067958	0.0123491	-0.00305
010	0.0063005	0.1050861	0.1338853	4.887E-05
001	0.1941539	-0.012739	0.2357018	-0.044104
110	-0.184075	-9.673776	-0.452025	8.4589015
101	-0.041077	0.0052319	0.0126083	-0.004903
011	-0.054824	-0.086226	0.0675667	-0.002958
200	-10.40849	-2.034601	-0.781174	-3.898158
020	-0.185052	-2.049123	-10.97003	-3.65872
002	-0.667144	-0.703552	-1.38033	-1.022955
210	-0.276565	-0.934586	0.1132374	0.1963083
201	-0.315201	0.1037481	-0.418756	0.548239
120	0.4299118	-0.638376	-0.197591	0.0916557
102	0.1958021	0.1499585	0.0039185	-0.008648
021	-0.183863	0.3631376	-0.32531	0.3546895
012	-0.028659	-0.092521	0.0091611	-0.027749
111	-0.117304	1.2430601	0.3630357	-0.621714
300	0.2402003	0.2355869	-0.002947	-0.090311
030	0.2041373	-0.178364	-0.657512	-0.101246
003	-1.626073	0.1537863	-1.547536	0.3751436
310	0.9742643	26.712001	6.8214445	-25.89364
301	0.2284221	0.1294556	0.0291898	-0.005386
220	1.2845096	17.604279	2.4262186	33.593885
202	0.0008044	2.6022288	4.991867	3.6857779
130	0.664085	30.812206	-1.310884	-23.77441
103	0.2918891	0.0920631	-0.044041	-0.021313
031	0.5239614	0.754418	-0.764858	0.082254
022	2.6206431	2.1565634	2.8336755	3.4774549
013	0.0164485	-0.194351	-0.045508	-0.075612
211	-0.026625	0.5120924	-0.025581	-0.021939
121	-0.093244	-0.40288	-0.000446	0.001038
112	0.3893577	-0.980804	-0.462174	0.9564952
400	29.54348	3.0301728	0.6717163	6.2335417
040	-0.985903	3.3968703	30.778271	5.2796577
004	3.9075167	1.1016488	5.0827304	1.3234163

Table.4: Polynomial coefficients (5th)

Subscript ijk	aijk	bijk	cijk	dijk
000	0.5540005	0.1607221	0.627414	0.2923769
100	-0.003082	0.0082679	-0.00094	-0.003092
010	-0.008376	0.0128783	-0.024158	0.0031332
001	0.036019	-0.053243	0.1559547	-0.068769
110	-0.159292	-9.826336	-0.533206	8.6498611
101	0.0313661	0.0027988	0.0545065	-0.015342
011	-0.67446	2.0878618	-3.818949	0.5140949
200	-10.5032	-2.147898	-0.795829	-4.086297
020	0.0302409	-1.966207	-10.84591	-3.558408
002	-0.429401	-0.729354	-1.468201	-1.089144
210	-2.934108	9.2457068	-17.81747	2.7076147
201	-0.945023	0.0540714	1.6218477	0.4439725
120	2.0784228	-1.27308	0.2150013	-0.023612
102	0.8488084	1.1724559	-0.338706	-0.14745
021	2.8051295	0.4788438	-0.204047	-0.191714
012	0.0346092	-0.113567	0.4347007	-0.046177
111	0.7376868	-3.345993	-1.477674	4.8640052
300	0.0392526	0.2322266	-0.047826	-0.053034
030	1.2798274	-2.767488	8.949011	-1.125878
003	-1.241775	0.7313603	-1.133757	1.1326467
310	0.9129897	27.705802	7.6026349	-26.78632
301	0.0572985	0.0082815	0.0186608	0.0203454
220	0.3948722	17.801068	1.6752833	34.125572
202	-0.277591	5.4534586	9.0638687	8.542952
130	0.4425258	31.384842	-1.414287	-24.7755
103	0.1444297	-0.035594	-0.039423	0.0115451
031	3.7976997	-10.44405	17.633149	-2.579639
022	0.0757029	0.048686	0.1257043	0.0684206
013	-0.172678	0.5376158	-1.176964	0.1618426
211	2.8414722	-10.14077	19.918005	-2.715082
121	-1.193885	0.036903	-0.309573	0.0563178
112	0.2182708	0.5409206	0.7655224	-1.127878
400	30.83454	3.2785105	0.2720145	6.5109728
040	-1.132895	3.4711996	30.683825	5.4270912
004	4.0968251	1.0709317	4.9072122	1.2672856
410	14.96319	-47.17617	84.978051	-12.15
401	17.657028	3.7285842	-1.479135	3.9291922
320	-6.137471	5.9081218	-3.891594	2.1075138
302	-5.40962	-4.798503	1.763734	1.1746688
230	1.6830168	-19.58905	36.775092	-4.649771
203	-0.807996	-9.023016	-13.9682	-14.95621
140	-6.967931	-0.10641	-0.148664	-0.631477
104	-1.300107	-2.241101	0.4678875	0.1755886
041	-2.074518	-0.133292	0.6713552	-0.007807
032	-5.810745	10.181561	-21.3433	3.4444078
023	-6.603827	0.3883118	8.4402948	3.807856
014	4.7472155	-12.55159	25.170679	-3.456203
311	-1.499357	24.629321	19.416706	-22.07202
131	-5.498046	14.122337	-2.651627	-24.77638
113	-0.873015	2.9391117	-0.607964	-2.74542
221	-24.6086	2.933534	-14.11229	9.8973287
212	-1.970914	5.6943527	-14.83992	1.8610398
122	0.0122804	-0.635433	0.3230265	0.2548061
500	1.4065487	-0.801068	1.7487951	-0.687626
050	-2.837976	12.01565	-41.0496	4.1474604
005	-0.564971	-0.309739	0.027728	-0.377729

for which it found according to this difference, and quality of image are related. Moreover, comparison with the case where other methods are used is also performed. In addition, the initial values of GA used by this research are the number of individuals 80, selection probability is 20% and mutation probability is 1%. And SPA is the number of repetition times is 300, the perturbation coefficient is 1 and the diffusion coefficient is 0.1.

Table 5 is an evaluation result of the reconstructed image quality of image E_1, E_2 and E at the time of setting the object size to 12×12 for the center of gravity of an input object as position(18, 18). Moreover, the same position(18, 18) with the case where a center-of-gravity object position is Table 5, and reconstructed image when an object size is 24×24 pixels. The evaluation E is shown in Table 6. Table 7 is an evaluation result of the reconstructed image quality of image E_1, E_2 and E at the time of setting the object size to 12×12 for the center of gravity of an input object as position(62, 114). Moreover, the same position(62, 114) with the case where a center-of-gravity object position is Table 7, and reconstructed image when an object size is 24×24 pixels. The evaluation E is shown in Table 8. Fig. 6～3 show the reconstructed image corresponding to Table 8～5.

In this case, since the value of E becomes small most in the 4th approximation, it turns out that result sufficient by the 4th approximation is obtained. It turns out that the reconstructed image quality of the reconstructed image by the error diffusion coefficient obtained by this 4th approximation excelled in little computing time as compared with the case of SPA is obtained. Moreover, even if it compares with the case where an error diffusion coefficient is drawn only in the center-of-gravity object position, it turns out that the value of the reconstructed image quality of image E is good.

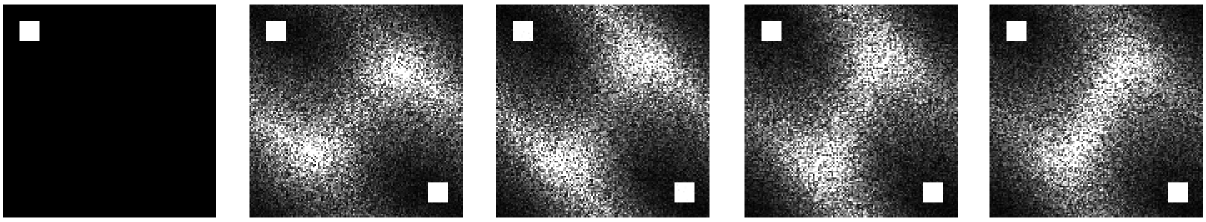
5. COMPARISON AT COMPUTING TIME

By the way, the system of this research can find for an error diffusion coefficient only by substituting an objective center-of-gravity position for expression (14) ～ (11). Therefore, computing time can be said to be very small as compared with calculation of 2D (Two-Dimension) FFT. In presumption and SPA of the optimal error diffusion coefficient using GA, it can be said that computational complexity is decided by the number of times of calculation of 2D FFT. In presumption of the optimal error diffusion coefficient using GA, when it make by the method shown in literature [9], 2D FFT will be performed 20000 times. When it is made to calculate by the method shown in literature [10] in SPA, two-dimensional FFT will be performed 300 times. However, 2D FFT does not perform the method of this research. Therefore, as compared with presumption and SPA of the optimal error diffusion coefficient using GA, it can be said that there is very little computational complexity.

6. CONCLUSIONS

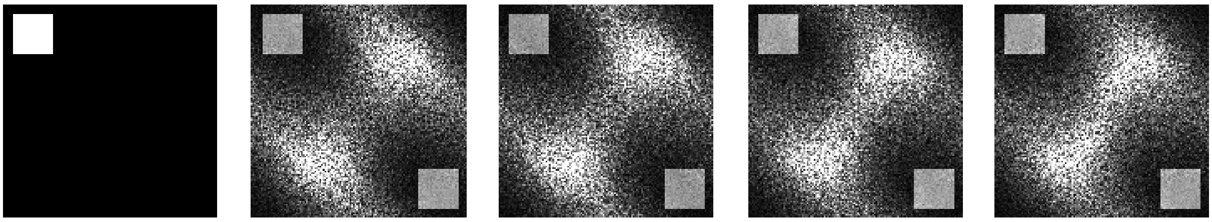
In this paper, the approximation expression of relations was drawn with the object position, the object size, and the error diffusion coefficient for CGH, and the validity was examined.

First the optimal error diffusion coefficient was drawn using GA, and it find for many positions and the relation of the error diffusion coefficient. The approximation



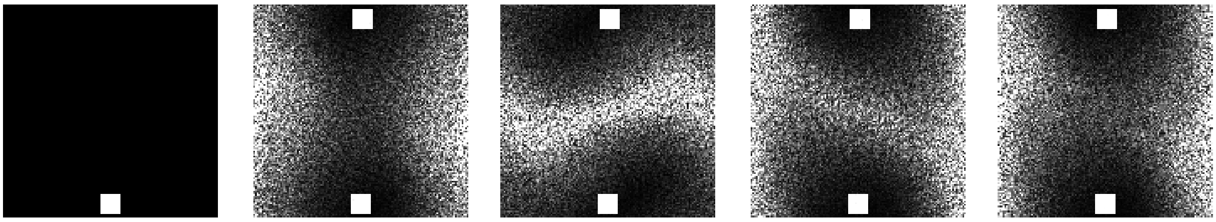
(a) Input image (b) GA (c) SPA (d) Previous Method (e) Proposed Method

Fig.3: Relationship between the diffusion coefficients and reconstructed image quality on object position (18,18) and object size 12×12.



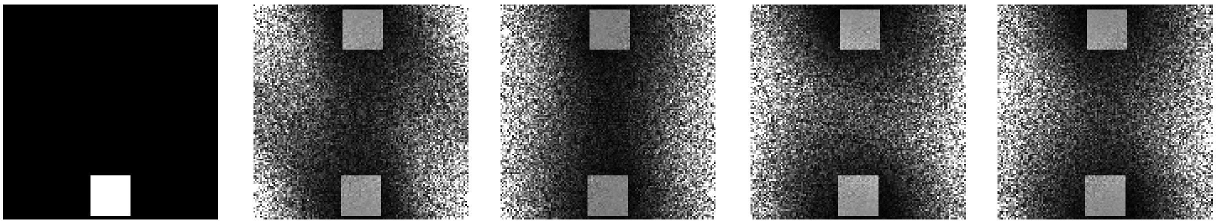
(a) Input image (b) GA (c) SPA (d) Previous Method (e) Proposed Method

Fig.4: Relationship between the diffusion coefficients and reconstructed image quality on object position (18,18) and object size 24×24.



(a) Input image (b) GA (c) SPA (d) Previous Method (e) Proposed Method

Fig.5: Relationship between the diffusion coefficients and reconstructed image quality on object position (62,114) and object size 12×12.



(a) Input image (b) GA (c) SPA (d) Previous Method (e) Proposed Method

Fig.6: Relationship between the diffusion coefficients and reconstructed image quality on object position (62,114) and object size 24×24.

expression of relations of the object position, the object size and an error diffusion coefficient was drawn using least mean square approximation from the result.

As a result, approximation turned out that the 4th is appropriate.

Next, it compared with this result and SPA which computing time can find for the optimal error diffusion coefficient early comparatively. As a result, it turned out that computing time can be shortened sharply. Moreover, it became clear to obtain the result of having excelled as compared with SPA also from a viewpoint of quality of image. Furthermore, since the object size was considered even if it compares with the case where it finds for an error diffusion coefficient from the center-of-gravity the object position, it became clear that the outstanding reproduction image is obtained. However, the object size is limited to the size of the grade which does not touch the noise by the effect of error diffusion method.

In this research, the expression of relations of the object position, object size, and a diffusion coefficient was drawn by making the object size into a square. If a center-of-gravity position is the same and makes the object size a square domain, it is thought that there is universality in a result. Moreover, in this research, although the input object was a two-dimensional image, about case like a dislocation 3D image whose input object is, it is a future subject.

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Table.5: Relationship between the diffusion coefficients and reconstructed image quality on object position (18,18) and object size 12×12.

Search Method	*a*	*b*	*c*	*d*	*E1*	*E2*	*E*
GA	-0.13928	-0.17549	-0.33426	0.350975	0.049609	0.004175	0.026892
SPA	-0.23412	-0.13326	-0.24242	0.390201	0.062235	0.008927	0.035581
Previous Method(5th)	-0.30343	-0.11543	-0.24609	0.335053	0.054327	0.007096	0.030712
2nd	-0.23063	-0.31143	-0.22649	0.231446	0.06801	0.01138	0.039695
3rd	-0.24942	-0.28044	-0.23543	0.234714	0.065742	0.00974	0.037741
4th	-0.30969	-0.12585	-0.29209	0.272379	0.057903	0.006523	0.032213
5th	-0.29415	-0.14575	-0.29457	0.265535	0.053927	0.006079	0.030003

Table.6: Relationship between the diffusion coefficients and reconstructed image quality on object position (18,18) and object size 24×24.

Search Method	*a*	*b*	*c*	*d*	*E1*	*E2*	*E*
GA	-0.24096	-0.1747	-0.20181	0.38253	0.100898	0.048637	0.074768
SPA	-0.24646	-0.17407	-0.22015	0.359324	0.115179	0.071072	0.093125
Previous Method(5th)	-0.26606	-0.19332	-0.21434	0.326277	0.109121	0.055971	0.082546
2nd	-0.21946	-0.32754	-0.21303	0.23997	0.136504	0.096651	0.116577
3rd	-0.22795	-0.31602	-0.21303	0.243005	0.128969	0.09206	0.110515
4th	-0.28789	-0.16053	-0.25448	0.297107	0.11013	0.062445	0.086288
5th	-0.29888	-0.09023	-0.31618	0.294705	0.121677	0.077716	0.099696

Table.7: Relationship between the diffusion coefficients and reconstructed image quality on object position (62,114) and object size 12×12.

Search Method	*a*	*b*	*c*	*d*	*E1*	*E2*	*E*
GA	0.485356	-0.04184	-0.35565	-0.11716	0.033052	0.00327	0.018161
SPA	0.212222	-0.29512	-0.4193	0.07336	0.052228	0.00731	0.029769
Previous Method(5th)	0.346705	-0.11776	-0.33194	-0.2036	0.042888	0.005492	0.02419
2nd	0.432924	0.000403	-0.5613	-0.00537	0.041988	0.005718	0.023853
3rd	0.424991	0.029054	-0.54518	-0.00077	0.045501	0.006022	0.025761
4th	0.41689	-0.07621	-0.3099	-0.197	0.037414	0.004275	0.020844
5th	0.442887	-0.11672	-0.2465	-0.1939	0.037514	0.004449	0.020981

Table.8: Relationship between the diffusion coefficients and reconstructed image quality on object position (62,114) and object size 24×24.

Search Method	*a*	*b*	*c*	*d*	*E1*	*E2*	*E*
GA	0.508333	0.091667	-0.12917	-0.27083	0.093584	0.049775	0.071679
SPA	0.640526	0.03338	-0.13446	-0.19163	0.094401	0.054549	0.074475
Previous Method(5th)	0.429872	-0.05917	-0.31868	-0.19228	0.103393	0.066536	0.084965
2nd	0.512867	0.03652	-0.43105	-0.01956	0.116682	0.096627	0.106655
3rd	0.475415	0.043078	-0.43888	-0.04263	0.121012	0.102267	0.111639
4th	0.498006	-0.01617	-0.3066	-0.17923	0.097167	0.060347	0.078757
5th	0.506509	-0.0264	-0.28125	-0.18584	0.10034	0.069362	0.084851