Noise Reduction of Image Using Sequential Method of Cellular Automata

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Abstract— **Cellular Automata is a discrete dynamical system that can be completely described in terms of local relation. For any given image, the system can save its features as well as increase or decrease the brightness of it locally through consideration of optimized transition in succession. These transitions in succession satisfy the function "Lyapunov" and have sequential movements. This study suggests the way of noise reduction for each image with the use of the Sequential Cellular Automata system. The mentioned transition in succession gives stable results with high-convergence performance to random noises and PSNR (Peak Signal-to-Noise Ratio) using histograms and MSE (Mean Square Error) for verification of effectiveness.**

***Index Terms*— Cellular Automata, Noise Removal, Transition Rule, Parameter, PSNR, sequential**

I. INTRODUCTION

IMAGE processing is an implementation, such as increasing the quality of an image, correcting the balance, or the analyzation and conversion of human's vision from an engineer's perspective. Particularly, a process of image enhancement which is important in image processing is the way of image improving for a better result. There will be several ways of doing it such as noise reduction, edge extraction, sharpening, and so forth. However, despite those many methods, a way of universal processing has not been developed because of diversity of objects, increasement of the amount of calculation, and simplicity in a way of processing. A digital image can be distorted by noises coming from an input device itself and errors. In the most cases of an image processing, reducing noise has a huge effect on the performance. Therefore we have to consider of reducing noise at composing system. Noises do not usually come with predictable patterns but rather in random patterns. Therefore it is not easy to define what noise is. It exists in many forms. In other words, noise can either occur with patterns or without.

Furthermore, the noise rate can be reduced by changing the brightness of pixels around the noise because noise does not harmonize with pixels around it. Frequency Domain Filtering and Space Domain Filtering represent ways of noise reduction in image. In Space Domain Filtering, there is an average filter, median filter, and so on. In Frequency Domain Filtering, there is a low-pass filter. Both average filters and low-pass filters can handle Gaussian noise quite well. However, it blurs definitions of the edge of the object or of where the brightness of pixels has changed dramatically. This is a well-known disadvantage of it. In terms of the median filter, it is suitable for dealing with impulse noise reduction but it is not flexible in that it creases the amount of calculation and implements to whole areas with the same filter.

In order to overcome these deficits mentioned above, Cellular Automata Method is needed. That is because this method deals locally so as to have flexibility to the unexpected. This study suggests a noise reduction algorithm using Sequential Cellular Automata. In sequential method, it has a dynamic characteristic in which pixels are sequentially converged and gathered into a fixed point. With the suggested method, we implement an image analyzation, comparing parameters and local transition in succession using the relations between neighboring pixels. We use sequential method for these approaches. Each regulation in succession defines the relation between neighboring pixels and it removes noises by either increasing or decreasing the brightness of the image locally. In a next chapter, we introduce Sequential Cellular Automata and algorithms for noise reduction in the one after.

The result of the test and the study of the result are as follows and in the last chapter, we conclude it.[1][2][3].

II. SEQUENTIAL CELLULAR AUTOMATA

Cellular Automata is a dynamic system which time, space, and status are all discrete. Every pixel gets a new status in terms of current status of mutually related neighbors and local rules. It develops, proliferates, and dies according to rules. One of the popular examples of Cellular Automata is a game called “game of life” by Conway. This considers states of pixels as 0 for a death and 1 for a birth and the pixel changes itself by the 8 neighbor pixels. A figure 1 shows how pixel changes.

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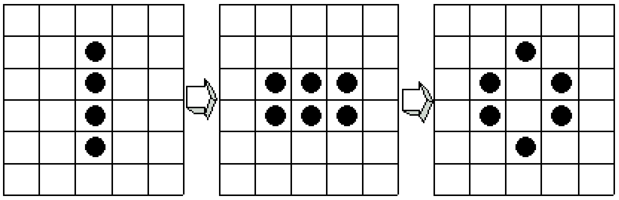


Regulation in success
i)When the main pixel is 1, neighbor pixel:
0, 1 ->0(death)
2, 3 ->1(birth)
Over 4 ->0(death)
ii)When the main pixel is 0, neighbor pixel:
3 ->1(birth)

Fig. 1. Game of life, Conway

Particularly, Automata can be used for image processing algorithms because it has a special form that will not change.[4][5][6]. The general Hamiltonian's formula is expressed by the equation (1)

$$H(x) = -\frac{1}{2}\sum_{(i,j)\in V}\delta(x_i, x_j) + \sum_{i\in I}\delta^*(b_i, x_i) \qquad (1)$$

But, $x_j \in Q = \{0,...,q-1\}$; the brightness values

δ, δ^* ; a symmetrical function, $(R \times R \to R)$

$\delta(a,b) = \delta(b,a)$; $\delta^*(a,b) = \delta^*(b,a)$

$(i,j) \in V$; pixel i, j are neighbors,

$I = \{1,..,n\}$, $V_i = \{j \in I : (i,j) \in V\}$, $b_i \in R$

A function used for i is expressed as below

$$H_i(x) = -\sum_{j\in V_j}\delta(x_i, x_j) + \delta^*(b_i, x_i) \qquad (2)$$

when the formula (1) satisfies Lyapunov function, then it converges.

$$\forall_i \in I: \quad H_i(\widetilde{x}) \le H_i(x), \quad \forall_X \in Q^n \qquad (3)$$

But, $x = (x_1,...,x_n)$,

$$\widetilde{x} = (x_1,...,x_{i-1}, f_i(x), x_{i+1},...,x_n)$$

For the formula (3), if it's sequential the verification of convergence is as follow. Let's put a_{ij} to a formula (4).

$$a_{ij} = \begin{cases} 1 & if\,(i,j) \in v \\ 0 & otherwise \end{cases} \qquad (4)$$

Obviously $A = (a_{ij})$ is $n \times n$ a symmetric matrix and $(i,j) \notin V$, $diagA = 0$. Therefore formula (1) can be expressed as

$$H(x) = -\frac{1}{2}\sum_{i\in I}\sum_{j\in I} a_{ij}\delta(x_i, x_j) + \sum_{i\in I}\delta^*(b_i, x_i) \qquad (5)$$

If we suppose the next status is

$\widetilde{x} = (x_1, \cdots, x_{i-1}, f_k(x), \cdots, x_n)$, by a symmetry of A and δ, δ^* .

$$\begin{aligned} \Delta H &= H(\widetilde{x}) - H(x) \\ &= -\frac{1}{2}\sum_{i\ne k}\sum_{j\ne k} a_{ij}\delta(x_i, x_j) - \sum_{j\in I} a_{kj}\delta(f_k(x), x_j) \\ &\quad + \sum_{i\ne k}\delta^*(x_i, x_j) + \delta^*(b_k, f_k(x)) + \frac{1}{2}\sum_{i\ne k}\sum_{j\ne k} a_{ij}\delta(x_i, x_j) \\ &\quad + \sum_{j\in I} a_{kj}\delta(x_i, x_j) - \sum_{i\ne k}\delta^*(b_i, x_j) - \delta^*(b_k, x_k) \end{aligned}$$

can be explained. Therefore,

$$\begin{aligned} \Delta H &= -\sum_{j\in V_k}\delta(f_k(x), x_j) \\ &\quad + \delta^*(b_k, f_k(x)) + \sum_{j\in V_k}\delta(x_k, x_j) - \delta^*(b_k, x_k) \\ &= H_k(\widetilde{x}) - H_k(x) \le 0 \end{aligned}$$

and formula (3) can be satisfied.

III. NOISE REDUCTION ALGORITHM

Suggested transition formula in succession are

$$f_i(x) = \begin{cases} x_i - T & if \left|\{j \in V_i \mid x_j < x_i\}\right| > \frac{|V_i|}{2}, T = 1,2,3,4,5 \\ x_i + T & if \left|\{j \in V_i \mid x_j > x_i\}\right| > \frac{|V_i|}{2}, T = 1,2,3,4,5 \\ x_i & otherwise \end{cases} \qquad (6)$$

Each pixel has a value between 0 to 255 and either 4 or 8 neighboring directions. $|V_i|$ tells a number of neighbors. With $\frac{|V_i|}{2}$, if there are 4 neighboring directions, it becomes 2 and becomes 4 if there are 8 neighboring directions.

In this paper, the sequential method to test noise reduction when T(parameter) is between 1 to 5. The suggested noise reduction method shows a form that the brightness of target pixels can go up and down, depending on the relation with its neighbors in transition in succession. Among neighbor pixels, we measure a number of both bigger brightness value and smaller brightness value against the target pixel.. If the value of the pixel is bigger than (a number of neighbor pixels) / 2, then you must increase the value of target pixel by T and vice versa. In other words, for better noise reduction, you only need to deal with areas that show dramatic difference with neighbor pixels in a value of the brightness. When you get optimal T, you get optimal transition in succession. Suggested transition rule (6) can be expressed as $\delta(a,b) = \min(a,b)$, $\delta^*(a,b) = ab$, $b_i = \frac{|V_i|}{2}$. considering formla (7) is a typical Hamiltonian's equation.

$$H(x) = -\frac{1}{2}\sum_{(i,j)\in V}\min(x_i, x_j) + \sum_{i\in I}\frac{|V_i|}{2}x_i \qquad (7)$$

If it is sequential, the verification of its convergence is as follows. Formula (1) can be described

$$\begin{aligned}(\Delta H)_i &= H_i(\tilde{x}) - H_i(x) \qquad (8)\\ &= \sum_{j\in V_i}(-\min(f_i(x), x_j) + \min(x_i, x_j)) + \frac{|V_i|}{2}(f_i(x) - x_i)\end{aligned}$$

Now we have to consider following 3 cases for formula (8).

i) $f_i(x) = \chi_i \Rightarrow (\Delta H)_i = 0$

ii) $f_i(x) = x_i + T$

$$\begin{aligned}(\Delta H)_i &= \sum_{j\in V_i}(-x_i - T + x_i) + \frac{|V_i|}{2}\\ &= -|\{j \in V_i \mid x_j > x_i\}| + \frac{|V_i|}{2}\end{aligned}$$

$f_i(x) = x_i + T \quad iff\ |\{j \in V_i \mid x_j > x_i\}| > \frac{|V_i|}{2}$ hence

$\therefore (\Delta H)_i < 0$

iii) $f_i(x) = x_i - T$

$$(\Delta H)_i = |\{j \in V_i \mid x_j \geq x_i\}| - \frac{|V_i|}{2}$$

$f_i(x) = x_i - T \quad iff\ |\{j \in V_i \mid x_j < x_i\}| > \frac{|V_i|}{2}$ hence

$\therefore (\Delta H)_i < 0$

Therefore, if it is sequential, the rule by transition rule (6) is a fixed convergence.

IV. RESULT AND CONSIDERATION

We have done the test on a Windows XP platform, using Delphi. We also used a 256 * 256 sized picture that has 256 values of brightness. A sequential method is applied. In this study, 3 different types of noises, Uniform-Distribution Noise, Gaussian Noise, and Impulse Noise are used. For Uniform-Distribution Noise, the same noise was applied to all the areas. For Gaussian Noise, it has got noises at where values of brightness are high. For Impulse Noise, noise applied that are symmetrical to the original image's brightness value. Neighbor pixels can be made by the amount of noise reduction and are stronger in noise reduction if the area is getting wider but it gets blur at the edge. So we use 4,8 neighbor directions for 3 by 3 area.

Figure 2 is shown when the framecount is 50 and T is 1. An (a) represents the original picture and (b) shows the picture after Uniform-Distribution Noise has applied to the original. As you can see, the histogram of (b) is showing that the histogram of the original has been disturbed by noise. A (c) and a (d) are the results of applying the suggested way. When we used 8 neighbor directions, it lost the image's accurate edge information although it was more efficient in noise reduction. The histograms indicate that there is effective noise reduction and data restoring of the original, showing the similar shapes to the original.

Figure 3 is after we applied to it with 50 for frame-count and 2 for T. Figure 4 shows the result after applying a frame-count of 50 and 3 for T. Finally, a figure 5 and a figure 6 also have a frame-count of 50 and use 4 and 5 for T respectively.

The results of Images with Gaussian Noise, Uniform-Distribution Noise and Impulse Noise applied are shown in Table 1,2,3.4, and 5.

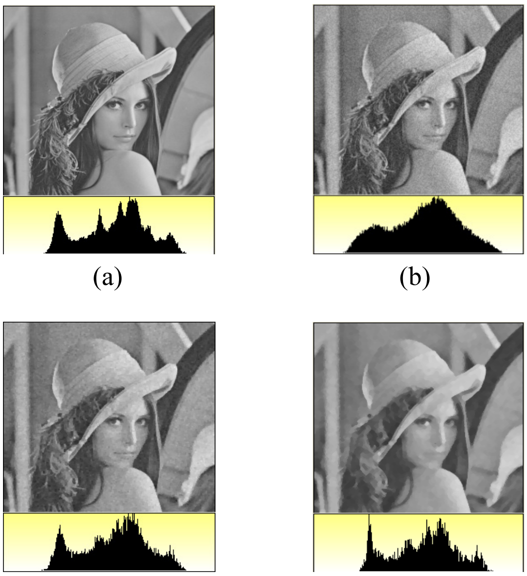
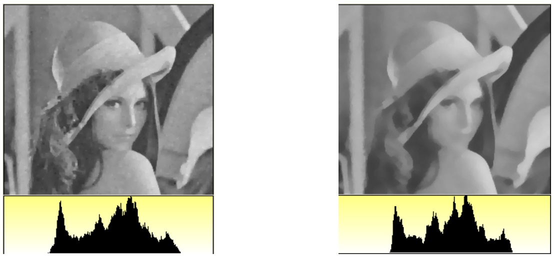
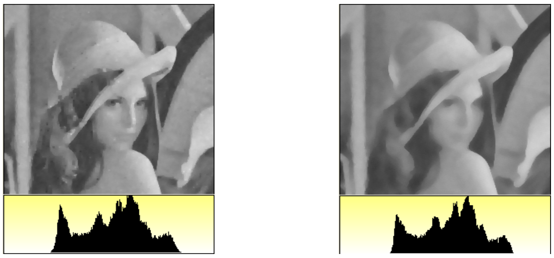

(a) (b)
(c) (d)

Fig. 2. T=1, an image transition in succession applied.
(a) Original image
(b) Image corrupted by uniform noise
(c) 4 ways sequential image
(d) 8 ways sequential image



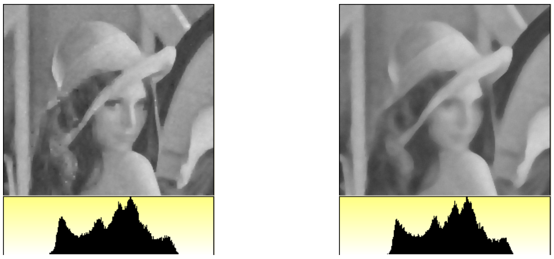
(a) (b)

Fig. 3. T=2, an image transition in succession applied
(a) 4 ways sequential image
(b) 8 ways sequential image



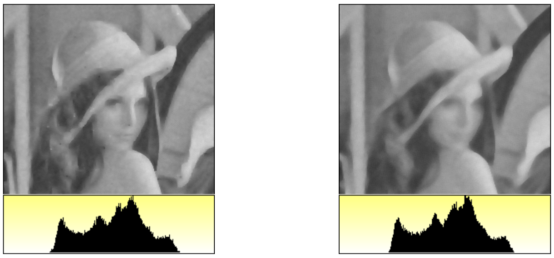
(a) (b)

Fig. 4. T=3, an image transition in succession applied
(a) 4 ways sequential image
(b) 8 ways sequential image



(a) (b)

Fig. 5. T=4, an image transition in succession applied
(a) 4 ways sequential image
(b) 8 ways sequential image



(a) (b)

Fig. 6. T=5, an image transition in succession applied
(a) 4 ways sequential image
(b) 8 ways sequential image

Table 1,2 3 represent the results after Gaussian Noise for Table 1 and Uniform-Distribution Noise for Table 2 and Impulse Noise for Table 3 have been applied. It shows the difference to the original in the brightness of pixels (mean, median value, standard deviation, PSNR, Time(μs), FrameCnt, TransCnt, Average in transition in succession) Using PSNR, we can compare the original to the result to find out the similarity between them. PSNR can be calculated by the difference of MSE (Mean Square Error) between two images and the higher its value is, the closer to the original. MSE(Mean Square Error) and PSNR can be expressed lower part equation

$$\mathrm{MSE} = \frac{1}{\mathrm{MN}} \sum_{m=1}^{M} \sum_{n=1}^{N} |P(m,n) - Q(m,n)|^{2}$$

where, P(m,n) : gray value of origin image (m,n),
Q(m,n) : gray valueof transition image(m,n),
MN : total pixel number of image

$$\mathrm{PSNR} = 10\log_{10}\frac{b^2}{\mathrm{MSE}}$$

where, b : peak value having 255 at 8 bit
PSNR is presented (dB)

TABLE I
IMAGE ANALYSIS OF GAUSSIAN NOISE REMOVAL(8WAY.SEQ)

	Mean	Median value	Standard Deviation	PSNR	Time	Frame Cnt	Trans-Cnt	Ave. Trans.
Origin	134.0	141	34.11	0.0	0	0	0	0
Noise	133.5	139	35.62	25.1	94	0	0	0
CA1	133.6	140	32.97	28.7	797	50	712342	10.87
CA2	149.0	153	28.60	21.1	781	50	1349764	20.60
CA3	184.4	187	28.50	12.5	797	50	1899082	28.98
CA4	197.7	216	42.71	8.2	796	50	2286056	34.88
CA5	160.2	172	60.67	9.0	813	50	2596927	39.63

TABLE II
IMAGE ANALYSIS OF UNIFORM NOISE REMOVAL(8WAY.SEQ)

	Mean	Median value	Standard Deviation	PSN	Time	Frame -Cnt	Trans-Cnt	Ave. Trans
Origin	134.0	141	34.11	0.0	0	0	0	0.00
Noise	133.5	139	35.15	26.8	0	50	2596927	39.63
CA1	133.6	139	32.78	29.7	797	50	705452	10.76
CA2	149.7	154	28.21	20.9	797	50	1362796	20.79
CA3	165.2	188	28.00	12.4	797	50	1884270	28.75
CA4	194.2	215	46.83	8.1	797	50	2303346	35.15
CA5	157.0	167	59.90	9.2	796	50	2625816	40.07

TABLE III
IMAGE ANALYSIS OF IMPULSE NOISE REMOVAL(8WAY.SEQ)

	Mean	Median value	Standard Deviation	PSNR	Time	Frame Cnt	Trans-Cnt	Ave. Trans.
Origin	134.0	141	34.11	0.0	0	0	0	0
Noise	133.9	141	34.56	27.8	0	0	0	0
CA1	134.0	140	33.04	28.5	718	50	274686	4.19
CA2	150.9	154	27.07	20.2	766	50	1219557	18.61
CA3	187.0	189	27.34	12.0	766	50	1817500	27.73
CA4	195.1	219	48.92	8.0	782	50	2245606	34.27
CA5	155.5	168	57.86	9.79	797	50	2534838	38.68

We studied to determine the best parameter values for Uniform-Distribution Noise, Gaussian Noise, Impulse Noise, FrameCnt, TransCnt, and the regulation in succession by comparing PSNR. PNSR is the value in comparison of the similarity to the original image. The higher PSNR value is, the closer it is to the original image. (FrameCnt stands for the number of times of regulation in succession of frame as well as the highest value PSNR has shown. FrameCnt is shown transition number of frame and resultof maxim PSNR) TransCnt represents the total value of pixels regulated in succession during progress. Average regulation in succession shows the number of times of regulation in succession of the value of dividing TransCnt by the number of pixel(65556 pixels) and the number of times of pixels that has been regulated in succession in average.

[Table 1] is the value of a result of applying Gaussian Noise Reduction to an image by the sequential way in 8 directions. The maximum PSNR value declines little amount comparing to FrameCnt which plummets as the parameter value rises.

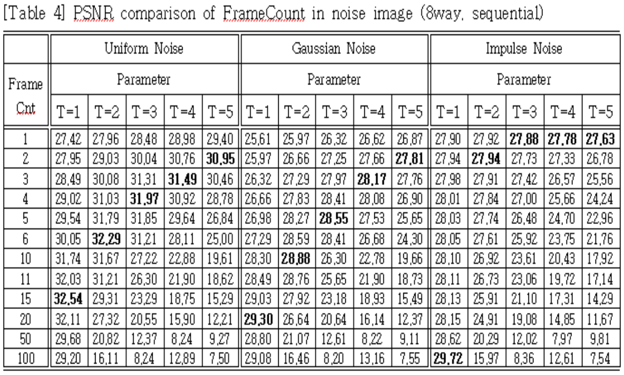
[Table 2] shows a result of image with Sequential Uniform-Distribution Noise Reduction in 8 directions. With the same Framecnt, we find out that the maximum value of PSNR decreases and the number of times of regulation in succession rises respectively as the value of T goes up. This is because the average number of times of regulation in succession of each pixel increases.

As [Table 3] suggests that 1 for T in a sequential way in 8 directions gives a good result in Impulse Noise. The reason why the result in Impulse Noise was not consistent is that we did not put in the drastic pixel value for the test.

We compared PSNR by applying 8-direction sequential way to an image, shown in [Table 4]. It shows that PSNR hits the maximum value when in Uniform-Distribution Noise with 1 for T and a FrameCnt of 15. In Gaussian Noise and Impulse Noise, PSNR gets the maximum value when a FrameCnt is 20 and 100 with 1 for T respectively.

As for [Table 5], we used 4-direction sequential way. In each Uniform-Distribution Noise, Gaussian Noise, and Impulse Noise, PSNR shows the maximum value when given a FrameCnt of 6 with 3 for T, a FrameCnt of 100 with 1 for T, and a FrameCnt of 100 with 1 for T respectively..

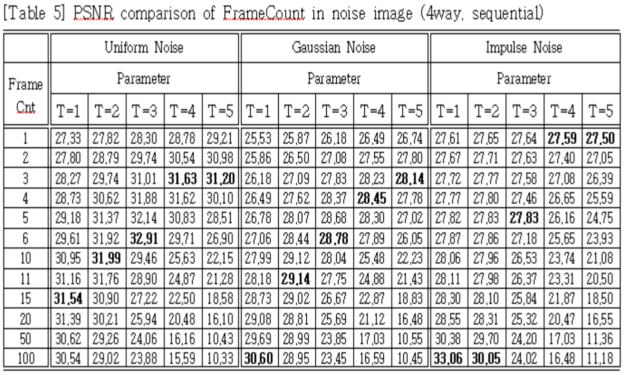
TABLE IV
PSNR COMPARISON OF FRAMECOUNT IN NOISE IMAGE(8 WAY. SEQUENTIAL)



[Table 4] PSNR comparison of FrameCount in noise image (8way, sequential)

Frame Cnt	Uniform Noise					Gaussian Noise					Impulse Noise				
	Parameter					Parameter					Parameter				
	T=1	T=2	T=3	T=4	T=5	T=1	T=2	T=3	T=4	T=5	T=1	T=2	T=3	T=4	T=5
1	27,42	27,96	28,48	28,98	29,40	25,61	25,97	26,32	26,62	26,87	27,90	27,92	**27,88**	**27,78**	**27,63**
2	27,95	29,03	30,04	30,76	**30,95**	25,97	26,66	27,25	27,66	**27,81**	27,94	**27,94**	27,73	27,33	26,78
3	28,49	30,08	31,31	**31,49**	30,46	26,32	27,29	27,97	**28,17**	27,76	27,98	27,91	27,42	26,57	25,56
4	29,02	31,03	**31,97**	30,92	28,78	26,66	27,83	28,41	28,08	26,90	28,01	27,84	27,00	25,66	24,24
5	29,54	31,79	31,85	29,64	26,84	26,98	28,27	**28,55**	27,53	25,65	28,03	27,74	26,48	24,70	22,96
6	30,05	**32,29**	31,21	28,11	25,00	27,29	28,59	28,41	26,68	24,30	28,05	27,61	25,92	23,75	21,76
10	31,74	31,67	27,22	22,88	19,61	28,30	**28,88**	26,30	22,78	19,66	28,10	26,92	23,61	20,43	17,92
11	32,03	31,21	26,30	21,90	18,62	28,49	28,76	25,65	21,90	18,73	28,11	26,73	23,06	19,72	17,14
15	**32,54**	29,31	23,29	18,75	15,29	29,03	27,92	23,18	18,93	15,49	28,13	25,91	21,10	17,31	14,29
20	32,11	27,32	20,55	15,90	12,21	**29,30**	26,64	20,64	16,14	12,37	28,15	24,91	19,08	14,85	11,67
50	29,68	20,82	12,37	8,24	9,27	28,80	21,07	12,61	8,22	9,11	28,62	20,29	12,02	7,97	9,81
100	29,20	16,11	8,24	12,89	7,50	29,08	16,46	8,20	13,16	7,55	**29,72**	15,97	8,36	12,61	7,54

TABLE V
PSNR COMPARISON OF FRAMECOUNT IN NOISE IMAGE (4WAY. SEQUENTIAL)



[Table 5] PSNR comparison of FrameCount in noise image (4way, sequential)

Frame Cnt	Uniform Noise					Gaussian Noise					Impulse Noise				
	Parameter					Parameter					Parameter				
	T=1	T=2	T=3	T=4	T=5	T=1	T=2	T=3	T=4	T=5	T=1	T=2	T=3	T=4	T=5
1	27,33	27,82	28,30	28,78	29,21	25,53	25,87	26,18	26,49	26,74	27,61	27,65	27,64	**27,59**	**27,50**
2	27,80	28,79	29,74	30,54	30,98	25,86	26,50	27,08	27,55	27,80	27,67	27,71	27,63	27,40	27,05
3	28,27	29,74	31,01	**31,63**	**31,20**	26,18	27,09	27,83	28,23	**28,14**	27,72	27,77	27,58	27,08	26,39
4	28,73	30,62	31,88	31,62	30,10	26,49	27,62	28,37	**28,45**	27,78	27,77	27,80	27,46	26,65	25,59
5	29,18	31,37	32,14	30,83	28,51	26,78	28,07	28,68	28,30	27,02	27,82	27,83	**27,83**	26,16	24,75
6	29,61	31,92	**32,91**	29,71	26,90	27,06	28,44	**28,78**	27,89	26,05	27,87	27,86	27,18	25,65	23,93
10	30,95	**31,99**	29,46	25,63	22,15	27,99	29,12	28,04	25,48	22,23	28,06	27,96	26,53	23,74	21,08
11	31,16	31,76	28,90	24,87	21,28	28,18	**29,14**	27,75	24,88	21,43	28,11	27,98	26,37	23,31	20,50
15	**31,54**	30,90	27,22	22,50	18,58	28,73	29,02	26,67	22,87	18,83	28,30	28,10	25,84	21,87	18,50
20	31,39	30,21	25,94	20,48	16,10	29,08	28,81	25,69	21,12	16,48	28,55	28,31	25,32	20,47	16,55
50	30,62	29,26	24,06	16,16	10,43	29,69	28,99	23,85	17,03	10,55	30,38	29,70	24,20	17,03	11,36
100	30,54	29,02	23,88	15,59	10,33	**30,60**	28,95	23,45	16,59	10,45	**33,06**	**30,05**	24,02	16,48	11,18

V. CONCLUSION

Most noise reduction in image processing has an effect on system performance.

However the existed fashion had some limitation such as distorting the image because that fashion did batch processing to the whole image. We also had to select the best filter for each image. In this paper, we represent Sequential Cellular Automata to solve these for noise reduction. An optimal regulation in successions is delivered by comparing Histogram, PSNR, and an average number of succession and finding optimal parameters. A suggested way concentrates on calculating the difference of brightness values. Therefore, it does not have to change all the brightness values. It only has to deal with necessary areas. Furthermore, for the best result, it does not have to repeat an operation artificially. This is because it uses transition in succession that converge in its best status and these are what gives the one we suggested more effectiveness over others. In noise reduction, the rule that takes the average value by increasing and decreasing values is applied. This gives reducing the blurriness at the edges and restoring of effective image information. What is more is that we learned that this suggested fashion reduces noise effectively regardless of structures of image and characters of noise by applying simple transition in succession to it repeatedly. This Sequential Cellular Automata can be used in many different areas. This suggested way of reducing noise will be able to be applied in an area where a bright value is important such as images pertaining to the medical field. In the future, however, further developments such as a new regulation in succession that has a distinct characteristic for various ways of image processing, applying to color images, general-purposed new image regulation in succession, mathematical modeling of processing time regarding each regulation in succession, and a way of calculating the difference to the original image quantitatively are necessary.

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