Image Processing by Cellular Neural Networks with Switching Two Templates

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***Abstract*—Cellular Neural Networks (CNN) were developed by Chua and Yang in 1988. The main characteristics of CNN are the local connection and the parallel signal processing. CNN consists of cells connected each other and they are arranged in a lattice. CNN is applied to the image processing because the its structure is similar to the image data. The performance of the CNN depends on the parameters which is called the template. When the template has a good influence of the processing, CNN can perform complex processing. In this study, we propose switching two templates CNN. The feature of the proposed method is switching two templates by using the maximum and the minimum output values surrounding the cell. We consider that cells are placed in the input image; edge, background, etc. We apply the proposed method to edge detection and investigate its performance.**

I. Introduction

Recently, many information have been existed in our life. In general, digital circuits are used for information processing. However, digital circuits cannot process many information in real time. Therefore, Neural Network was proposed. Neural Network is based on the nervous system of humans and can process parallel signals. Then, Cellular Neural Networks (CNN) was introduced by Chua and Yang in 1998 [1]. CNN is paired Neural Network with the Cellular Automata. Hence, CNN has been successfully used for various high-speed parallel signals processing applications such as image processing, pattern recognition and so on [2].

CNN consists of the cells connected each other and the structure of CNN resembles the structure of the image data. Thus, CNN has been suitable for various image processing. The performance of CNN depends on the parameters which is called the template. The template represents strength of connection between cells. If the template influences exactly, CNN can perform complex processing. Additionally, various applications for image processing and pattern recognition of CNN have been reported [3]-[6].

In image processing of CNN, it is difficult to process complex parts of the input image; edge, background, etc. Some researches are reported that it is possible to process complex parts by switching two templates which have the different feature. Therefore, we propose, in this study, a new CNN method of switching two templates; 3×3 and 5×5 templates by using the maximum and the minimum output values surrounding the center cell. We apply the proposed method to edge detection and investigate its performance.

II. Cellular Neural Networks [1]

In this section, we explain the structure and the processing flow of CNN. Basic unit circuit of CNN is called cell. The cell consists of linear element and nonlinear element. CNN contains an array in a reticular pattern of many cells. In image processing of CNN, processing is conducted by making one cell to one pixel in the image data. We show a two dimensional array composed of M $\times$ N identical cells arranged in M rows and N columns. The array of CNN and the circuit of cell are shown in Fig. 1 and 2.

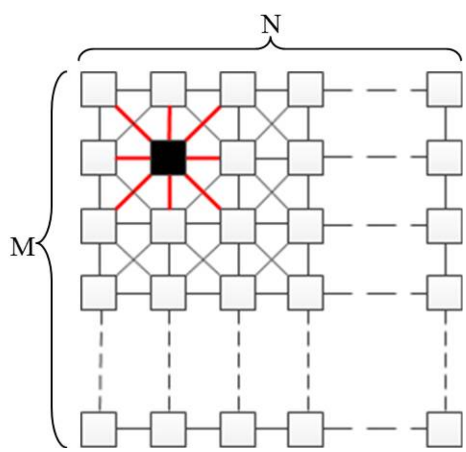

Fig. 1. The structure of CNN.

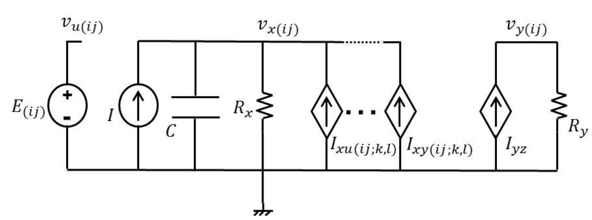

Fig. 2. The circuit of cell.

A cell couples with only adjacent cells. Adjacent cells interact with one another and the other cells in the neighborhood have an indirect influence. The range which some cells have

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influenced one cell is defined by neighborhood. State and output equation of cell are described as followed.

State Equation :

$$\frac{dv_{x(ij)}}{dt} = -v_{x(ij)} + \sum_{k=i-r}^{i+r} \sum_{l=j-r}^{j+r} A_{(i,j;k,l)} v_{y(kl)}(t) + \sum_{k=i-r}^{i+r} \sum_{l=j-r}^{j+r} B_{(i,j;k,l)} v_{u(kl)}(t) + T. \quad (1)$$

Output Equation :

$$v_{y(ij)}(t) = \frac{1}{2}(|v_{x(ij)}(t)+1| - |v_{x(ij)}(t)-1|). \quad (2)$$

v_x, v_y and v_u are state value, output value and input value. In Eq (1), A, B and T are feedback template, feedforward template and threshold. These parameters determine the performance of CNN. In Fig. 3, output equation represents piece-wise nonlinear function. In image processing of CNN, output value v_{y} determines output color.

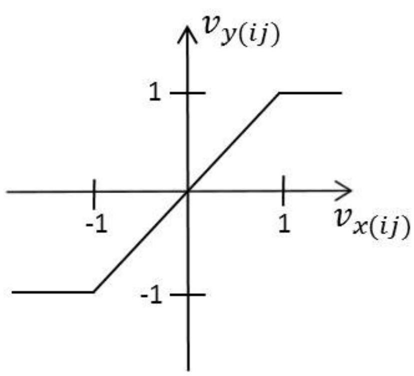
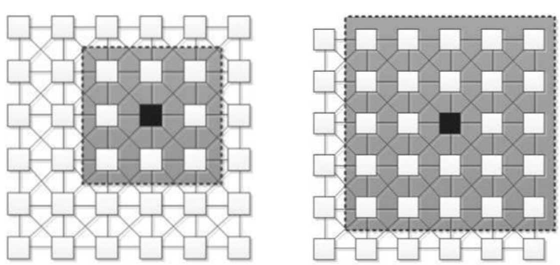


Fig. 3. Piece-wise nonlinear function.



(a)3×3 (b)5×5

Fig. 4. System of neighborhood.

In image processing of CNN, the size of system of neighborhood must be determined. In Fig. 4, cell of system of neighborhood is shown. Generally, the size which is used for image processing is 3×3. In this study, we use 3×3 and 5×5 in combination. In Fig. 5, block diagram of image processing with CNN is shown.

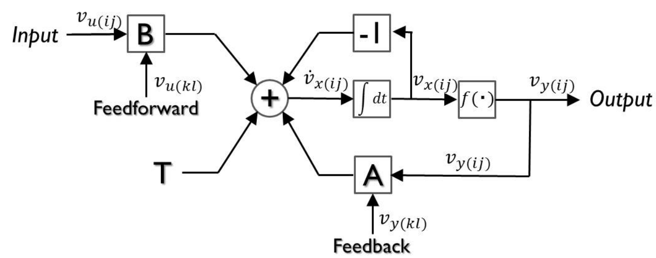


Fig. 5. Block diagram.

III. PROPOSED METHOD

In this section, we explain the proposed method. The feature of the proposed method is switching two templates by using the maximum and the minimum output values (v_{ymax}: cell's maximum output value, v_{ymin}: cell's minimum output value) surrounding the center cell. The concept of the proposed method is shown in Fig. 6. The processing steps of the proposed method are described as followed.

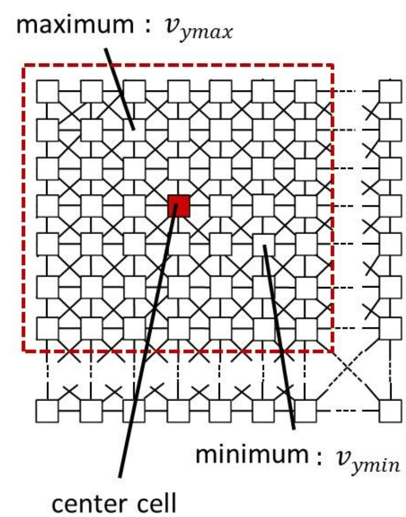


Fig. 6. Proposed CNN.

Step 1 : First, decide the center cell. Then, find the v_{ymax}, and v_{ymin} from the 7×7 neighborhood.

Step 2 : Secondly, determine if the center cell has the maximum or the minimum output value.

Step 3 : Thirdly, state and output equation are described as follows in the proposed method.

State equation with the 3×3 *template* :

$$\begin{aligned}\frac{dv_{x(ij)}}{dt} &= -v_{x(ij)} + \sum_{k=i-r_1}^{i+r_1} \sum_{l=j-r_1}^{j+r_1} A_1(i,j;k,l)v_{x(kl)}(t) \\ &+ \sum_{k=i-r_1}^{i+r_1} \sum_{l=j-r_1}^{j+r_1} B_1(i,j;k,l)v_{u(kl)}(t) + T_1 \\ &(|i-k| \le r_1 \ , \ |j-l| \le r_1). \end{aligned} \quad (3)$$

State equation with the 5×5 *template* :

$$\begin{aligned}\frac{dv_{x(ij)}}{dt} &= -v_{x(ij)} + \sum_{k=i-r_2}^{i+r_2} \sum_{l=j-r_2}^{j+r_2} A_2(i,j;k,l)v_{x(kl)}(t) \\ &+ \sum_{k=i-r_2}^{i+r_2} \sum_{l=j-r_2}^{j+r_2} B_2(i,j;k,l)v_{u(kl)}(t) + T_2 \\ &(|i-k| \le r_2 \ , \ |j-l| \le r_2). \end{aligned} \quad (4)$$

Output equation :

$$v_{y(ij)}(t) = \frac{1}{2}(|v_{x(ij)}(t)+1| - |v_{x(ij)}(t)-1|). \quad (5)$$

Step 4: In case that the center cell has the maximum or the minimum output value, it is applied 5×5 template. In the other case, it is processed by using 3×3 template.

These processing steps are applied to all cells in the input image and repeated every 0.005 [τ].

IV. SIMULATION RESULTS

In this section, we show simulation results of the edge detection by using the proposed method. We show two examples and using templates of the edge detection templates [7]-[8].

Edge detection templates :

3×3 *template* :

$$A = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix},$$

$$B = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}, \ T = -1. \quad (6)$$

5×5 *template* :

$$A = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$B = \begin{bmatrix} -1 & -1 & -1 & -1 & -1 \\ -1 & 0 & 0 & 0 & -1 \\ -1 & 0 & 16 & 0 & -1 \\ -1 & 0 & 0 & 0 & -1 \\ -1 & -1 & -1 & -1 & -1 \end{bmatrix}, \ T = -1. \quad (7)$$

Fig. 7. Simulation results 1. (a) Input image. (b) Simulation result of the 3×3 CNN. (c) Simulation result of the 5×5 CNN. (d) The proposed method. (e) The difference between (c) and (d).

In one example, Fig. 7 shows the input image and simulation results by using only 3×3 template, only 5×5 template, the proposed method and the difference between 5×5 CNN and the proposed method. The defocused parts of the input image are the left-side pillar and the woman's silhouette. Therefore, it is difficult to detect the edge lines of these parts clearly. In Fig. 7(b), the defocused parts are not detected by using 3×3 template. On the other hand, in Fig. 7(c), the defocused parts are detected by using 5×5 template. However, some noise remains at woman's hat and silhouette and edge lines are thick. In Fig. 7(d), the edge lines such as the pillar, and woman's silhouette can be detected clearly and thinly. In addition, noise is removed especially woman's hat and silhouette. Edge detection of using the 3×3 template can detect thin edge lines and insusceptible to noise effect. Hence, the proposed method could detect thin edge lines and removed noise by switching two templates.

Figure 8 shows the simulation results for another input image. The input image is boat and the defocused parts are text and rope. In Fig. 8 (b), edge lines are not detected clearly using the 3×3 template. On the other hand, in Fig. 8 (c), edge lines of the defocused parts can be detected using the 5×5 template. However, edge lines are thick such as the defocused parts. In Fig. 8 (d), the proposed method can detect thin edge

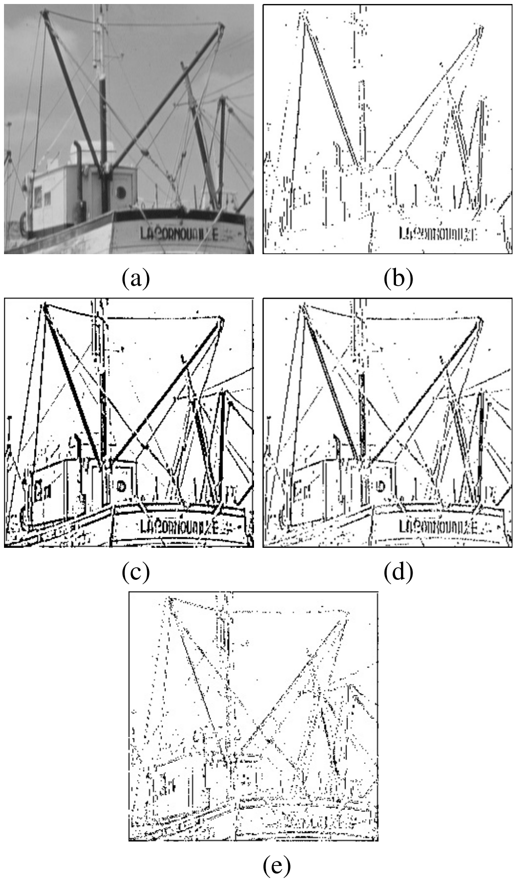


Fig. 8. Simulation results 2. (a) Input image. (b) Simulation result of the 3×3 CNN. (c) Simulation result of the 5×5 CNN. (d) The proposed method. (e) The difference between (c) and (d).

lines such as the defocused parts clearly and receive less noise effect. Hence, the 5×5 template is applied to the defocused parts of the input image and the 3×3 template is applied to the periphery of cells.

We have confirmed that the proposed method could perform edge detection for general image. The proposed method could detect most edge including the defocused parts. Then, we evaluate performance of the proposed method for edge detection. We compare the proposed method and the conventional CNN with input images which contain a gradient region. In each input image, boundary of two parts become defocused as it goes top of the image. In Fig. 9, we show input images.

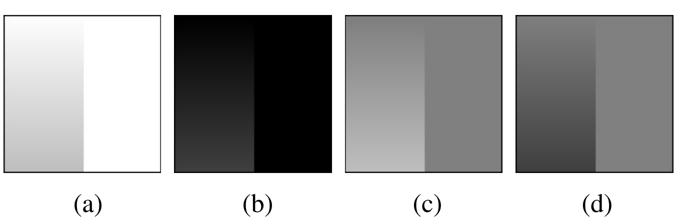


Fig. 9. Input images. (a) Gradient (white to whitish gray) and white. (b) Gradient (black to blackish gray) and black. (c) Gradient (gray to whitish gray) and gray. (d) Gradient (gray to blackish gray) and gray.

We define the range from the bottom to the top of the image boundary is $0[\%]$ to $100[\%]$ and evaluate the proposed method by detected boundary line. In Tab. 1, we show detection rate of each input image.

TABLE I
DETECTION RATE [%].

	Proposed method	3×3 CNN	5×5 CNN
Figure 9(a)	62	25	73
Figure 9(b)	64	34	82
Figure 9(c)	75	34	80
Figure 9(d)	70	34	84

Ideal edge is assumed as a 1-pixel-wide line on the boundary of two regions. From Tab. 1, the detection rate by using 5×5 template is high and it can detect boundary line in each case. However, detected edge line is a heavy line as 2-pixel-wide. Then, the detection rate will decrease considering this point. On the other hand, we have confirmed that detection rate of the proposed method is improving about twice compared with CNN with using 3×3 template.

From these simulation results, the proposed method is more effective than the conventional CNN for edge detection.

V. Conclusions

In this study, we have proposed a new CNN method of switching two templates. In the proposed method, the 3×3 and 5×5 templates were switched by using the maximum and the minimum output values containing the center cell in the 7×7 neighborhood. We applied the proposed method to edge detection. From the simulation results, the proposed method could detect thin edge lines of the defocused parts in the input image. Therefore, the proposed method is more effective than the conventional CNN for edge detection. In the future works, we would like to investigate the performance of the proposed method for another image processing.

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