Two-Layer Cellular Neural Networks with Layer of Delay Output

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***Abstract*—Cellular Neural Networks (CNN) has been developed as a high-speed parallel signal processing platform by L. O. Chua and L. Yang in 1988. Then, generalized two-layer CNN model has been proposed. Two-layer CNN efficiently behaves compared to single-layer CNN for many applications of image processing. In this study, we propose a new two-layer CNN system including layer of delay output. In the proposed system, second-layer CNN is added a delay output value by the delay type feedback template. In addition, first-layer CNN receives information including delay output from second-layer CNN. We apply the proposed system to edge detection and investigate its performance.**

I. Introduction

In recent years, our life teems with information by growth of high information society. In order to conduct parallel signal and flexible processing like human, Neural Network has been proposed. Neural Network is based on the nervous system of human. Additionally, Neural Network can perform expression of nonlinear operating characteristics. Then, Cellular Neural Networks (CNN) was introduced by L. O. Chua and L. Yang in 1988 [1]. The idea of CNN was inspired from the architecture of the cellular automata and Neural Network. CNN has local connectivity property and its structure resembles the retina. CNN has been successfully used for various high-speed parallel signal processing applications such as image processing, pattern recognition and so on. CNN is composed of the basic analog circuit units called cell. The performance of CNN depends on the parameters which are called the template. Each cell is connected to its neighboring cells according to the template. Additionally, various applications for image processing and pattern recognition have been reported [2]-[5].

In image processing of CNN, it is difficult to process complex parts of the input image; edge, background, etc. In order to process complex parts of the input image, Cellular Neural Networks with delay output (DCNN) has been proposed [6]. The feature of DCNN is added a delay output value by the delay type feedback template. DCNN depends on the past information as well as the current information in the processing. However, noise effect can be observed in the output image of using DCNN.

In this study, we propose a new CNN system including layer of delay output. The proposed system is based on the structure of two-layer CNN. In the proposed system, second-layer CNN is added a delay output value by the delay type feedback template. In addition, first-layer CNN receives information including delay output from second-layer CNN. We consider that noise effect can be reduced by receiving only important information of the input image. Therefore, two layers are connected by only one coupling template. We apply the proposed system to edge detection and investigate its performance.

II. Conventional System

A. Cellular Neural Networks

CNN has M by N processing unit circuits calld cells. The cell consists of linear element and nonlinear element. Cells are arranged in a reticular pattern to M line N row. In Fig 1, we show the structure of CNN. In image processing of CNN, each cell is corresponded to each pixel of the input image.

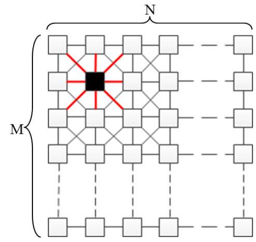

Fig. 1. The structure of CNN.

Each cell is connected to its neighboring cells according to the template. Generally, the template is given for all cells except for boundary cells. The template perform the influence amang cells. The state and output equation of cell are shown as follows.

State Equation :

$$\frac{dv_{xij}}{dt} = -v_{xij} + \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} A_{(i,j;k,l)}v_{ykl}(t) + \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} B_{(i,j;k,l)}v_{ukl}(t) + I \quad (|i-k| \le r\ ,\ |j-l| \le r). \tag{1}$$

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Output Equation :

$$v_{yij}(t) = \frac{1}{2}(|v_{xij}(t)+1| - |v_{xij}(t)-1|). \quad (2)$$

v_x, v_y and v_u are state value, output value and input value. In Eq. (1), A, B and I are feedback template, feedforward template and threshold. These parameters determine the performance of CNN.

B. Cellular Neural Networks with Delay Output (DCNN)

DCNN is added a delay output value by D template to the conventional single-layer CNN. In the conventional CNN, it can perform image processing only depending on current information. On the other hand, DCNN depends on the past information as well as the current information. In Fig. 2, we show the block diagram of DCNN. In the block diagram, D is the delay type feedback template and τ is delay time. The state and output equation of DCNN are shown as follows.

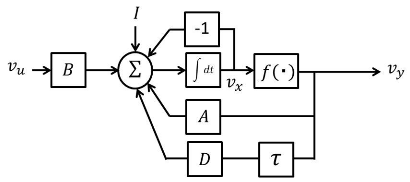


Fig. 2. Block diagram of DCNN.

State Equation ($t \le \tau$) :

$$\begin{aligned}\frac{dv_{xij}}{dt} &= -v_{xij} + \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} A_{(i,j;k,l)}v_{ykl}(t) \\ &+ \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} B_{(i,j;k,l)}v_{ukl}(t) + I \\ &(|i-k| \le r \ , \ |j-l| \le r). \end{aligned} \quad (3)$$

State Equation ($t > \tau$) :

$$\begin{aligned}\frac{dv_{xij}}{dt} &= -v_{xij} + \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} A_{(i,j;k,l)}v_{ykl}(t) \\ &+ \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} B_{(i,j;k,l)}v_{ukl}(t) \\ &+ \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} D_{(i,j;k,l)}v_{ykl}(t-\tau) + I \\ &(|i-k| \le r \ , \ |j-l| \le r). \end{aligned} \quad (4)$$

Output Equation :

$$v_{yij}(t) = \frac{1}{2}(|v_{xij}(t)+1| - |v_{xij}(t)-1|). \quad (5)$$

C. Two-Layer Cellular Neural Networks

In Fig 3, we show the block diagram of the conventional two-layer CNN. The conventional two-layer CNN is constructed by two conventional single-layer CNN. Two conventional single-layer CNN are coupled by two coupling templates C_{12} and C_{21}. They are used to transfer output values between both layers.

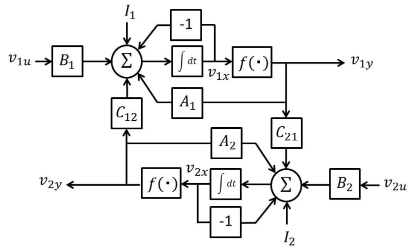


Fig. 3. Block diagram of two-layer CNN.

III. Proposed System

In Fig. 4, we show the block diagram of the proposed system. The structure of the proposed system is based on conventional two-layer CNN. In the proposed system, two conventional single-layer CNN are coupled by only one coupling template C_{12}. In addition, second-layer CNN includes the output with time delay [6]. Second-layer CNN depends on the past information as well as the current information like the processing of DCNN. The state equation and the output equation of each layer are shown as follows.

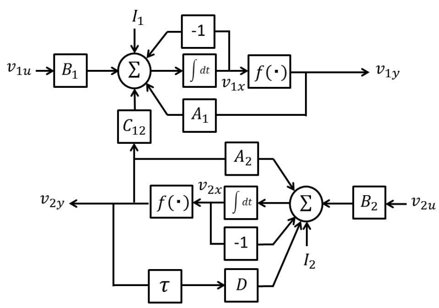


Fig. 4. Block diagram of proposed system.

State equation of first-layer CNN :

$$\begin{aligned}\frac{dv_{1xij}}{dt} &= -v_{1xij} + \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} A_{1(i,j;k,l)}v_{1ykl}(t) \\ &+ \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} B_{1(i,j;k,l)}v_{1ukl}(t) \\ &+ \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} C_{12(i,j;k,l)}v_{2ykl}(t) + I_1 \\ &(|i-k| \le r, \ |j-l| \le r). \end{aligned} \quad (6)$$

State equation of second-layer CNN ($t \leq \tau$) :

$$\frac{dv_{2xij}}{dt} = -v_{2xij} + \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} A_{2(i,j;k,l)} v_{2ykl}(t) + \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} B_{2(i,j;k,l)} v_{2ukl}(t) + I_2 \quad (|i-k| \leq r,\ |j-l| \leq r). \tag{7}$$

State equation of second-layer CNN ($t > \tau$) :

$$\frac{dv_{2xij}}{dt} = -v_{2xij} + \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} A_{2(i,j;k,l)} v_{2ykl}(t) + \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} B_{2(i,j;k,l)} v_{2ukl}(t) + \sum_{k=i-r}^{i+r}\sum_{l=j-r}^{j+r} D_{(i,j;k,l)} v_{2ykl}(t-\tau) + I_2 \quad (|i-k| \leq r,\ |j-l| \leq r). \tag{8}$$

Output equation of first-layer CNN :

$$v_{1yij}(t) = \frac{1}{2}(|v_{1xij}(t)+1| - |v_{1xij}(t)-1|). \tag{9}$$

Output equation of second-layer CNN :

$$v_{2yij}(t) = \frac{1}{2}(|v_{2xij}(t)+1| - |v_{2xij}(t)-1|). \tag{10}$$

IV. SIMULATION RESULTS

We show some simulation results for edge detection by using the proposed system. In this simulation, templates for edge detection in the proposed system are shown as follows [7].

Edge detection template :

$$A_1 = A_2 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix},$$
$$B_1 = B_2 = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix},$$
$$D = \begin{bmatrix} -0.12 & -0.12 & -0.12 \\ -0.12 & 0.1 & -0.12 \\ -0.12 & -0.12 & -0.12 \end{bmatrix},$$
$$I_1 = I_2 = -1. \tag{11}$$

Coupling template :

$$C_{12} = \begin{bmatrix} 0 & -0.05 & 0 \\ -0.05 & 0.49 & -0.05 \\ 0 & -0.05 & 0 \end{bmatrix}. \tag{12}$$

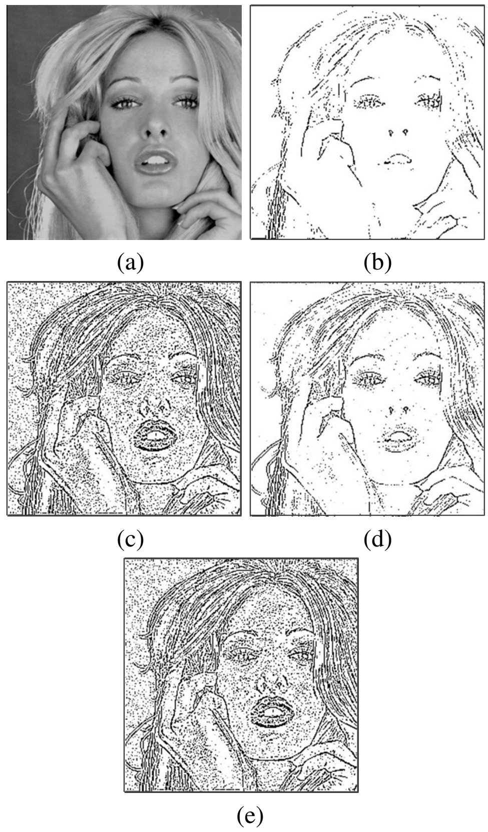
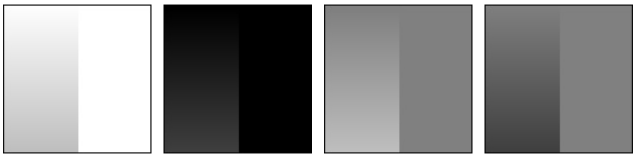


Fig. 5. Simulation results 1. (a) Input image. (b) Simulation result of the conventional CNN. (c) Simulation result of DCNN. (d) Simulation result of first-layer CNN in the proposed system. (e) Simulation result of second-layer CNN in the proposed system.

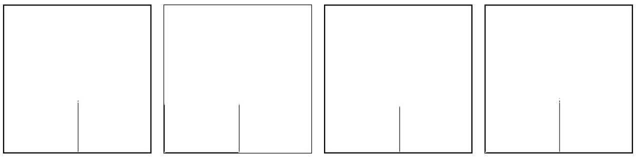
In Fig. 5, we show the input image and simulation results by the conventional CNN, DCNN and the proposed system of each layer. The defocused part of the input image is the outline of woman's face and hands. It is difficult to detect the edge lines of that part clearly. In Fig. 5(b), the defocused part is not detected by the conventional CNN. On the other hand, in Fig. 5(c), the defocused part is detected by DCNN. However, some noise remains in the output image. In the proposed system, the edge lines such as the defocused part can be detected clearly. In addition, noise is reduced compared to the method of DCNN. We consider that first-layer CNN receives the characteristic of woman's outline from second-layer CNN. Therefore, amount of characteristic in the input image is detected more effectively than the conventional CNN.

We have confirmed that the proposed system could perform edge detection for general image. The proposed system could detect characteristic of the input image including the defocused parts. Then, we evaluate the performance of the proposed system for edge detection. We compare the proposed system to the conventional system with input images which contain a gradient region. In Fig. 6, we show input images. In each input image, boundary of two parts become defocused as it goes top of the image.



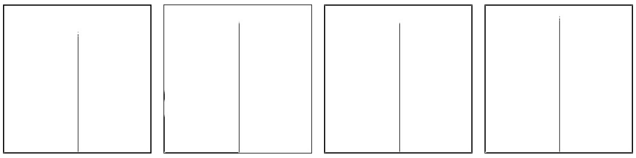
(a) (b) (c) (d)

Fig. 6. 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.



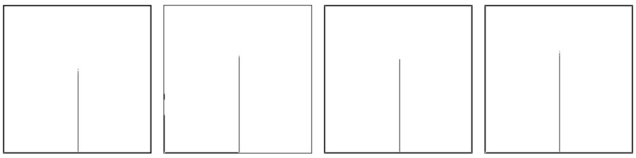
(a) (b) (c) (d)

Fig. 7. Simulation results using the conventional CNN. (a) Output image for Fig. 6(a). (b) Output image for Fig. 6(b). (c) Output image for Fig. 6(c). (d) Output image for Fig. 6(d).



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

Fig. 8. Simulation results using DCNN. (a) Output image for Fig. 6(a). (b) Output image for Fig. 6(b). (c) Output image for Fig. 6(c). (d) Output image for Fig. 6(d).



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

Fig. 9. Simulation results using the proposed systyem. (a) Output image for Fig. 6(a). (b) Output image for Fig. 6(b). (c) Output image for Fig. 6(c). (d) Output image for Fig. 6(d).

Figure 7 shows simulation results of using the conventional system. In any cases, it is difficult to detect boundary. Figure 8 shows simulation results of using DCNN. The boundary of two parts is detected better than using the conventional CNN. In each case, high detection rate can be observed by including delay output. On the other hand, Fig. 9 shows simulation results of using the proposed system. The proposed system can detect the boundary better than using the conventional CNN.

In Tab. 1, we show detection rate of each input image using the conventional CNN, DCNN and the proposed system. We define that the range from the bottom to the top of the boundary is $0[\%]$ to $100[\%]$. Ideal edge is assumed as the boundary of two regions. From Tab. 1, the detection rate by using DCNN is high and it can detect boundary line in each case. However, in image processing of general image, noise effect can be observed by using DCNN. Then, detection rate will decrease considering this point. On the other hand, we have confirmed that detection rate of the proposed system is improving about two times compared with the conventional CNN.

TABLE I
DETECTION RATE [%].

	Conventional CNN	DCNN	Proposed system
Figure 6(a)	25.00	80.61	55.51
Figure 6(b)	33.59	88.92	66.40
Figure 6(c)	33.59	88.38	63.84
Figure 6(d)	33.59	91.16	67.68

V. CONCLUSIONS

In this study, we have proposed a new CNN system including layer of delay output. In the proposed system, second-layer CNN depends on the past information by the delay type feedback template D and first-layer CNN receives that information. We applied the proposed system to edge detection. From the simulation results, the proposed system could detect edge of the defocused part in the input image. Therefore, the proposed system is more effective than the conventional CNN for edge detection. In the future works, we would like to investigate the performance of the proposed system for another image processing. In addition, we consider that some one-way coupling templates are switched by using the output values of first-layer CNN and second-layer CNN.

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