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Circuit Design of Two Template Cellular Neural Networks for the Observation of Oscillation Phenomena

Yasuteru Hosokawa[1], Yoko Uwate[2], and Yoshifumi Nishio[2]

1 Shikoku University
Furukawa, Ohjin-Cho, Tokushima 771-1192 Japan
Phone:+81-88-665-1300
E-mail: hosokawa@keiei.shikoku-u.ac.jp

2 Tokushima University
2-1 Minami-Josanjima-Cho, Tokushima 770-8506 Japan
Phone:+81-88-656-7470
E-mail: {uwate,nishio}@ee.tokushima-u.ac.jp

Abstract

Some interesting phenomena concerned with oscillations can be observed in Two Template Cellular Neural Networks (TTCNN) propsed by Fujii et al [13]. However, these phenomena were confirmed on computer simulations from a mathematical model only. A circuit experimentation is an important factor for investigations of circuit systems. In this study, a circuit of TTCNN have been designed. An oscillation, which is the same as the mathematical model, could be confirmed by SPICE Simulations of the designed circuit.

1. Introduction

Cellular Neural Networks (CNN) proposed by Chua and Yang [1][2] have many application posibilities. For instance, image processing, pattern recognition, associative memory and so on have been considered. The main features are an uniform structure consisting of local connections, continuous-time dynamics and parallel processing. Especially, the uniform structure is an import feature for the implementation as an integrated circuit. On CNNs, all cells and signal wires are located uniformly. Therefore, the implementation as an integrated circuit is easy [3]-[5]. However, almost all modified CNNs [6]-[12], which have many advantages compared to the conventional CNN, have a disadvantage in the point of view from a circuit implementation. These CNNs need many complicated signal wire layouts, many amplitudes, many operation signal and/or so on.

Two template CNN proposed by Fujii et al [13] is designed by paying attention to a circuit implementation. Two different cloning template sets are located as a checkered pattern. Thus, the structure is almost the same as the conventional CNN. The difference of a conventional CNN is only operation signals for values of a second cloning template set. Although some interesting phenomena concerned with oscillations can be observed, these were confirmed on computer simulations from a mathematical model only.

In this study, a circuit of two template cellular neural networks is designed. An oscillation, which is the same as the mathematical model, can be confirmed by SPICE Simulations of the designed circuit.

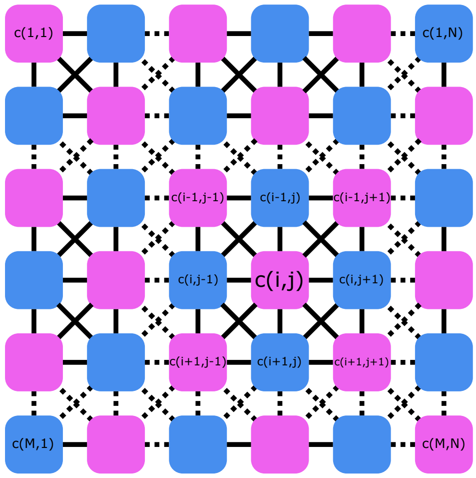

Figure 1: Structure of two template cellular neural networks. Different cloning template sets are applied to magenta cells (Cell α) and blue cells (Cell β).

2. Archtecture of Two Template CNN

The system model of Two Template CNN as shown in Fig. 1 has a two-dimensional M by N array structure. Each cell in the array is denoted as $c(i,j)$, where (i,j) is the position of the cell, $1 \leq i \leq M$ and $1 \leq j \leq N$. The coupling radius is assumed to be one. Cells having one cloning template are called as cell α and the other cells are called as cell β. These two types of the cells are placed as a checkered pattern.

A difference between the conventional CNN and the proposed system is only the number of signal lines for cloning templates. Therefore, the proposed system is suitable for IC implementation as the same as the conventional CNN.

The state equations of the cells are given as follows:
1: For cell α.

$$\frac{dx_{ij}}{dt} = -x_{ij} + I_\alpha + \sum_{c(k,l)} \boldsymbol{A}_\alpha(i,j;k,l) y_{kl} + \sum_{c(k,l)} \boldsymbol{B}_\alpha(i,j;k,l) u_{kl} \qquad (1)$$

2: For cell β.

$$\frac{dx_{ij}}{dt} = -x_{ij} + I_\beta + \sum_{c(k,l)} \boldsymbol{A}_\beta(i,j;k,l) y_{kl} + \sum_{c(k,l)} \boldsymbol{B}_\beta(i,j;k,l) u_{kl} \qquad (2)$$

$\boldsymbol{A}_{\{\alpha\beta\}}(i,j;k,l)$, $\boldsymbol{B}_{\{\alpha\beta\}}(i,j;k,l)$ and $I_{\{\alpha\beta\}}$ are called as the feedback coefficient, the control coefficient and the bias current, respectively. The variables u, x and y are the input, state and output variables of the cell, respectively. $\boldsymbol{A}_\alpha$, $\boldsymbol{B}_\alpha$, $\boldsymbol{A}_\beta$ and $\boldsymbol{B}_\beta$ are 3×3 matrices, which can be described for example:

$$\boldsymbol{A}_\alpha = \begin{pmatrix} \boldsymbol{A}_\alpha(i,j;i-1,j-1) & \boldsymbol{A}_\alpha(i,j;i-1,j) & \boldsymbol{A}_\alpha(i,j;i-1,j+1) \\ \boldsymbol{A}_\alpha(i,j;i,j-1) & \boldsymbol{A}_\alpha(i,j;i,j) & \boldsymbol{A}_\alpha(i,j;i,j+1) \\ \boldsymbol{A}_\alpha(i,j;i+1,j-1) & \boldsymbol{A}_\alpha(i,j;i+1,j) & \boldsymbol{A}_\alpha(i,j;i+1,j+1) \end{pmatrix}. \qquad (3)$$

The output equation of the cell is given as follows:

$$y_{ij} = 0.5(|x_{ij}+1| - |x_{ij}-1|). \qquad (4)$$

3. Settings for Oscillation Phenomena in TTCNN

In this section, settings for Oscillation Phenomena in TTCNN are described. In order to simplify the system parameters, cloning templates are set as symmetry as follows.

$$\boldsymbol{A}_\alpha = \begin{pmatrix} -p & q & -p \\ q & r & q \\ -p & q & -p \end{pmatrix}, \ \boldsymbol{B}_\alpha = 0, \ I_\alpha = 0,$$
$$\boldsymbol{A}_\beta = \begin{pmatrix} p & -q & p \\ -q & -r & -q \\ p & -q & p \end{pmatrix}, \ \boldsymbol{B}_\beta = 0, \ I_\beta = 0. \qquad (5)$$

Boundary conditions are set as periodic. The input values do not concern to the result because $\boldsymbol{B}_\alpha = \boldsymbol{B}_\beta = 0$.

By results of many computer simulations, the minimum number of an observation of oscillatory phenomena is four. Namely, the simplest architecture for an oscillation consists of four cells as shown in Fig. 2. In the conventional CNN, symmetry cloning templates could not oscillate. This point is one of the important feature of TTCNN.

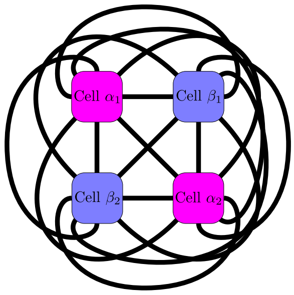

Figure 2: Minimum architecture of TTCNN for the oscillation.

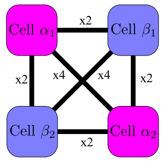

Figure 3: Streamlined minimum architecture of TTCNN for the oscillation.

One of the parameter sets obtained oscillation phenomena is $p = 2$, $q = 4$, and $r = 1$. In this case, the architecture can be converted into Fig. 3. In Fig. 2, each cell has four/two lines connecting another cell, because the boundary condition is set as periodic. Additionally, cloning template values of these four/two lines are same. Therefore, by changing four/two times cloning template value of one line and eliminating the other lines, Fig. 2 is streamlined into Fig. 3. This architecture is designed as an electric circuits.

4. Circuit Design

Figure 4 shows a circuit schematic of Cell $\alpha 1$ as an example schematic of Cells. The cell obtains input singals from output of each cell including itself. All input signals are multiplied by cloning template values and these values are summed. These are realized by adder-substractor part of Fig. 4. Basically, the cloning template values are set as values of R_{a1-1}, R_{a1-2}, R_{a1-3}, and R_{a1-4}. Specifically, $p = \frac{R_1}{R_{a1-3}}$, $q = \frac{R_1}{R_{a1-2}} = \frac{R_1}{R_{a1-4}}$, and $r = \frac{R_1}{R_{a1-1}}$. In case of a negative value, an inverter is also added. The inverter consists of OPamp and two resistors. For instance, one inverter consists of OPamp U_6, resisters R_{10}, and R_{11}. The voltage as multiplied and summed signals is converted into a current for the state value. The state value is shown as voltage C_1 in the RC part. The limiter part as shown in Fig. 4 converts the state value to output value. Namely, This part means the output function and value 1 in this system is defined as a threashold voltage of the diode in this part.

A difference from other cells is only adder-substracter part. Since this part includes cloning template values, registance values and the number and the position of the inveter are difference points. The other parts are complimentally same.

5. SPICE Simulation

Figure 5 shows one of SPICE simulation result of Fig. 3 including Fig. 4. Each state values of cells are shown. Fol-

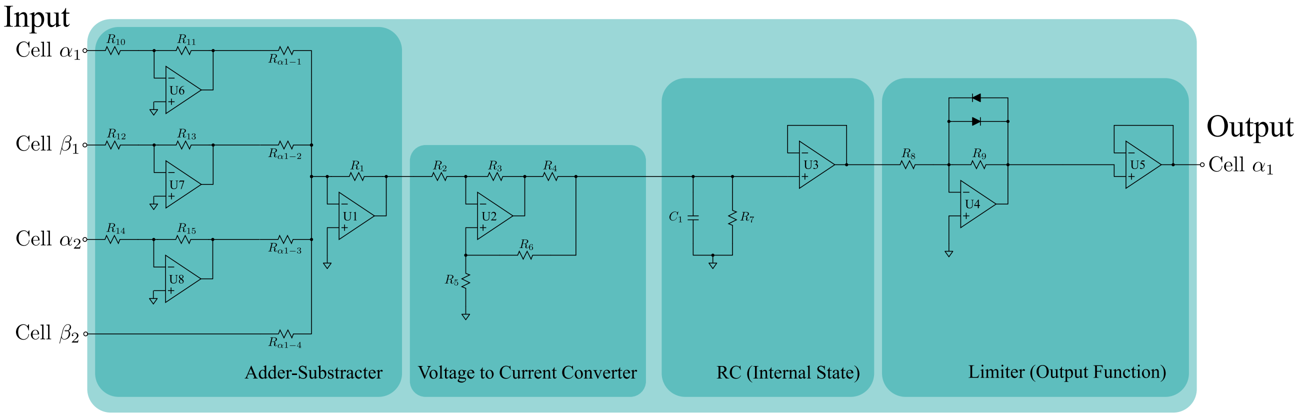

Figure 4: Circuit schematic of Cell $\alpha 1$ of the designed circuit.

lowing settings are applied. $R_1 = R_3 = R_6 = R_8 = R_9 = R_{11} = R_{12} = R_{\alpha 1-1} = 10.0$ [kΩ]. $R_1 = R_{a1-1} = 40$ [kΩ], $R_2 = R_5 = 100$ [kΩ], $R_3 = R_6 = R_7 = R_8 = R_9 = R_{10} = R_{11} = R_{12} = R_{13} = R_{14} = R_{15} = 10$[k$\Omega$], $R_4 = 1$[kΩ], and $R_{a1-2} = R_{a1-3} = R_{a1-4} = 5$[k$\Omega$]. The simulator is LTspice [14]. Voltages of capasitors $\mathrm{VC}_{\mathrm{Cell}\alpha 1} = 0.5$, $\mathrm{VC}_{\mathrm{Cell}\alpha 2} = -0.5$, $\mathrm{VC}_{\mathrm{Cell}\beta 1} = 0.5$, and $\mathrm{VC}_{\mathrm{Cell}\beta 2} = 0.5$ are set as initial values. An oscillation can be obsereved. The amplitudes of Cells α and β are about 4[V] and 2[V]. The bias of Cells α and β are about ± 3[V] and 0[V]. In this system, value 1 is about 0.5[V], bacause it is defined as a diode threashold voltage. Therefore, the amplitudes of Cells α and β are about 8 and 4. The bias of Cells α and β are about ± 6 and 0. This result is almost the same as a corresponding result of mathematical model as shown in Fig. 6.

6. Conclusion

In this study, a circuit of TTCNN which consists of four cells have been designed. By SPICE simulation, an oscillation which is the same as the mathematical model could be confirmed. Thus, the circuit design is reasonable.

As future works, a circuit implementation and increasing the number of cell are considered.

Acknowledgment

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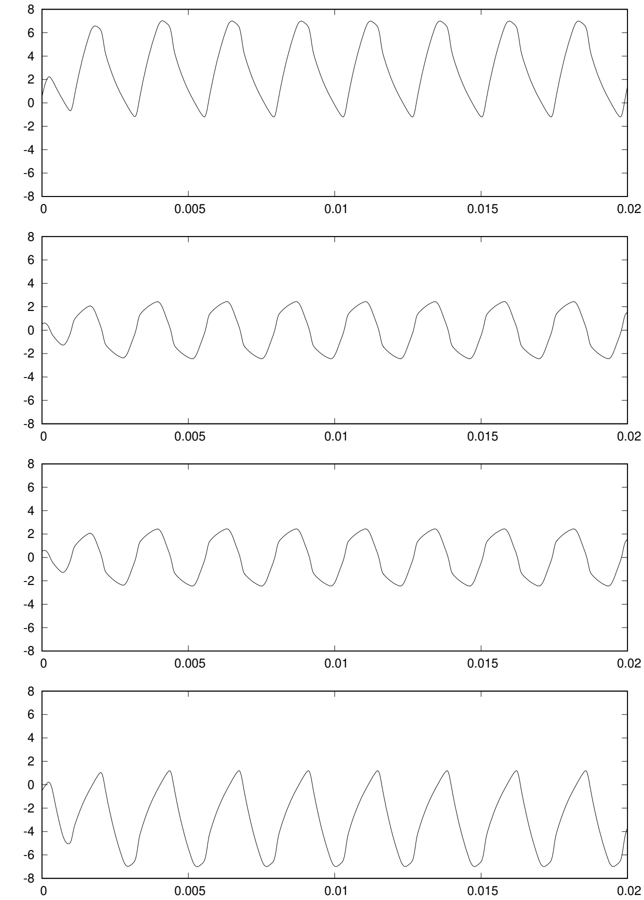

Figure 5: SPICE Simulation result of the designed circuit. Vertical axes shows voltages [V] of four capasitors. First line: Cell $\alpha1$, Second line: Cell $\beta1$, Third line: Cell $\beta2$, and Fourth line: Cell $\alpha2$. Horizontal axes shows time [s].

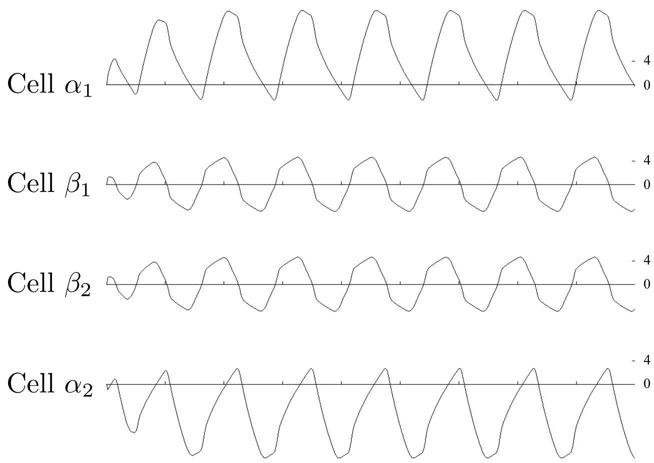

Figure 6: Computer simulation result of the mathematical model of TTCNN. The number of cell is four. $p = 2$, $q = 4$, and $r = 1$. Time step is 0.01. Initial values are $x_1 = x_2 = x_3 = 1$ and $x_4 = -1$. These variables are corresponding to internal state values of each cell.

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