Proceedings of ITC-CSCC 2000, Pusan, Korea

Discrete-Time CNN Using Chaos Circuits with Nonlinear Function Controllability

Kei EGUCHI†, Fumio UENO†, Toru TABATA†, Hongbing ZHU††, and Yuuki HAMASAKI†

† Dept. of Information and Computer Sciences, Kumamoto National College of Technology,
2659–2, Suya, Nishigoshi, Kikuchi, Kumamoto, 861-1102 Japan
Tel. : +81–96–242–6072
E–mail : eguti@ee.knct.ac.jp
†† Dept. of Electrical and Computer Engineering, Kumamoto University,
2–39–1 Kurokami, Kumamoto–shi, 860-8555 Japan

Abstract

In this paper, a CNN using 1-dimensional chaos circuits with controllable nonlinear functions is proposed. The proposed CNN consists of $p \times q$ chaos circuits which are called cell circuits. The nonlinear functions of the cell circuits can be controlled by employing fuzzy scheme. Thanks to the controllability of the nonlinear functions, the proposed circuit can adjust transition behavior of the CNN, electronically. Furthermore, the chaotic behavior of the cell circuit which is a portion of the proposed CNN is simple since the cell circuit is a 1-dimensional chaos circuit. To confirm the validity of the circuit design, SPICE simulations were performed concerning the proposed CNN.

1 Introduction

Chaos is one of the most frequently encountered phenomena in the study of nonlinear dynamical systems. For this reason, to analyze and optimize the nonlinear dynamical systems, several approaches which exploit the chaotic behavior have been proposed. Among others, the studies employing CNNs (Cellular Neural Networks) which consist of chaos generators attract many researchers' attension. These studies exploiting CNNs have been realized on a digital computer. However, in case that the CNN consists of a large number of cells, the studies realized on a digital computer take a long computational time. For this reason, many researcher's have shown prototypes of the CNN using chaos circuits [1],[2]. These CNNs exploit Chua's chaos circuits [1],[2] as the cell circuits. Chua's circuit which is designed by voltage-mode techniques is one of the most famous 3-dimensional circuits. Although the studies exploiting the CNNs can be achieved by employing Chua's circuit, the cell circuits which satisfy the following design aspects are desirable. 1. To control the transition behavior of the CNN, the flexibility of the cell circuit such as controllability of the nonlinear function is desirable. 2. Simplicity of the chaotic behavior of the cell circuit is favorable since it enables the users to analyze the behavior of the network with ease. 3. To implement onto the chip, compatibility with a standard IC technology is desirable. These features enable the CNNs to get into experimental tools for the large scale networks.

In this paper, a discrete-time CNN using 1-dimensional chaos circuits with controllable nonlinear functions is proposed. The proposed CNN consists of $p \times q$ chaos circuits which are called cell circuits. The chaotic behavior of the cell circuit which is a portion of the proposed CNN is simple since the cell circuit is a 1-dimensional chaos circuit. The nonlinear functions of the cell circuits can be controlled by employing fuzzy scheme. Thanks to the controllability of the nonlinear functions, the proposed circuit can adjust transition behavior of the CNN, electronically. Furthermore, the cell circuit synthesized using switched-current (SI) techniques is suitable for integration. To confirm the validity of the circuit design, SPICE simulations were performed concerning the proposed CNN.

2 Architecture

The proposed CNN consists of $p \times q$ 1-dimensional chaos circuits called cell circuits. The dynamics of the proposed CNN is based on the following equation:

$$\mathrm{X}_{i,j}(t+1) = \mathrm{F}(\mathrm{X}_{i,j}(t)) + \mathrm{Q}, \qquad (1)$$

where t is the cycle of the CNN, Q is effect from other cells, and $\mathrm{F}(\cdot)$ is a piecewise-linear function determined by fuzzy scheme.

Figure 1 shows the block diagram of the cell circuit which is a portion of the proposed CNN. In the fuzzy rule block, the matching degrees ${}^{i,j}W_n$'s are determined by the following equation:

$${}^{i,j}W_n = \mu_n(\mathrm{X}_{i,j}(t)) \qquad (n = 1, 2, \ldots, k), \quad (2)$$

where n $(= 1, \ldots, k)$ denotes the fuzzy label for the input $\mathrm{X}_{i,j}(t)$ and μ_n's are the triangular membership functions.

In the defuzzifier block, the output fuzzy set, ${}^{i,j}W_1/{}^{i,j}S_1 + \ldots + {}^{i,j}W_k/{}^{i,j}S_k$, is defuzzified by the center of area (COA) method, where ${}^{i,j}S_n$ is the singleton's element, / is Zadeh's separator, and + is the

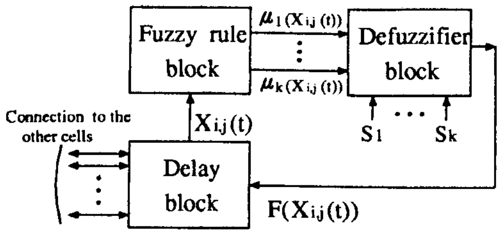


Fig.1 Block diagram of the cell circuit.

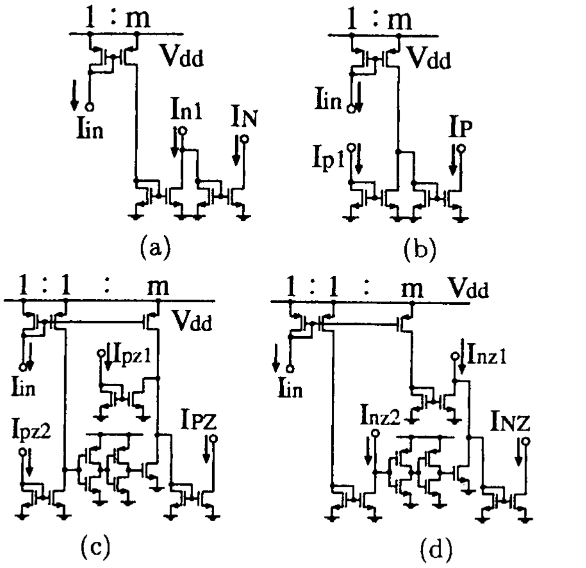


Fig.2 Membership function circuit (MFC). (a) N. (b) P. (c) PZ. (d)NZ.

union operation. The defuzzified output, $F(X_{i,j}(t))$, is given by

$$F(X_{i,j}(t)) = \frac{\sum_{n=1}^{k} {}^{i,j}S_n \, {}^{i,j}W_n}{C}, \quad (3)$$

where C is a constant value. This defuzzified output is obtained as the output of the defuzzifier block in Fig.1. In the delay block, the output of the defuzzifier block is delayed by one cycle and it is fed back to the input of the fuzzy rule block. The connection to the other cells is realized in the delay block.

The functional blocks in Fig.1 will be implemented in the following section.

3 Circuit Structure

The proposed CNN is implemented by using switched-current (SI) techniques. The fuzzy rule block in Fig.1 is realized by using membership function circuits (MFC's) shown in Fig.2. The synthesis of the membership function circuits is based on the following equations:

$$I_N = (I_{n1} - mI_{in}),$$
$$I_P = (mI_{in} - I_{p1}),$$

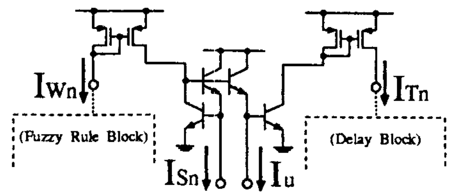


Fig.3 Translinear multiplier/divider circuit (TLC).

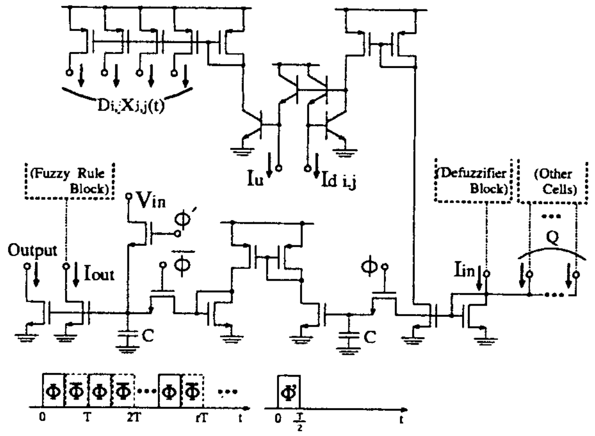


Fig.4 SI track & hold circuit (THC).

$$I_{PZ} = (mI_{in} \ominus I_{pz1})u(I_{pz2} - I_{in}),$$
$$I_{NZ} = (mI_{nz1} \ominus I_{in})u(I_{in} - I_{nz2}), \quad (4)$$

where $u(\cdot)$ is a unit step function, m is a parameter realized by the current-copying ratio of the current mirror, and $\ominus$ is a bounded-difference operator.

The defuzzifier block in Fig.1 is realized by using translinear multiplier/divider circuits (TLC's) shown in Fig.3. The TLC realizes the following equaiton:

$$I_{Tn} = \frac{I_{Sn}}{I_u} I_{Wn}, \quad (5)$$

where $I_{Wn} \geq 0$, $I_{Sn} \geq 0$, and $I_u > 0$.

The delay block in Fig.1 is realized by an SI track & hold circuit (THC) shown in Fig.4. In the THC, the timing of a unit delay is controlled by the switches ϕ and $\bar{\phi}$. The THC realizes the wired-sum connection to the other cells as well as the unit delay. The diffusion coefficient $D_{i,j}$ is realized by

$$D_{i,j} = I_{di,j}/I_u. \quad (6)$$

The connection to the other cells is open when the $I_{di,j} \neq 0$. In the delay block, the initial value $X_{i,j}(0)$ of the cell circuit is given by V_{in}.

4 Simulation

To confirm the validity of the circuit design, SPICE simulations are perfomed regarding to the proposed circuit. As the examples of nonlinear dynamical phenomena, chaos synchronization phenomenon and traveling wave phenomenon are observed. In SPICE simulations, SI cell circuit shown in Fig.5 was used. The

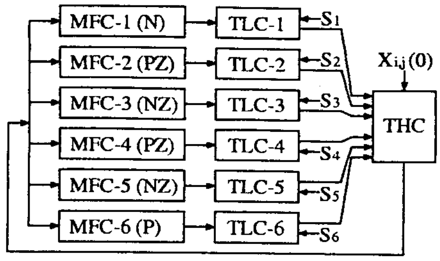


Fig.5 Block diagram of the cell circuit used in SPICE simulations.

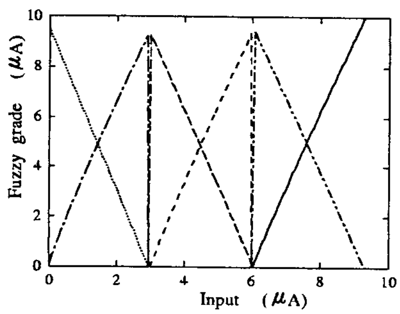


Fig.6 Membership functions.

cell circuit shown in Fig.5 can realize the nonlinear function which has 4 boundary points.

4.1 Cell Circuit

Firstly, to confirm the validity of the circuit design, the SPICE simulations were performed concerning the SI cell circuit. Figure 6 shows the membership functions obtained by SPICE simulations. In this figure, the fuzzy-grade interval [0, 1] is represented by [$0\mu A$, $9\mu A$]. The ratio of the current mirror, m, in Fig.2 was set to $m = 3$. The current sources in the membership function circuits were set to the values shown in Table.1. Figure 7 shows the nonlinear function of the SI cell circuit obtained by SPICE simulations. The current sources I_{Sn}'s which correspond to the values of the singletons were set to the values shown in Fig.7. As one can see from Fig.7, the proposed circuit can control the shape of the nonlinear function, electronically.

4.2 Chaos Synchronization

To observe the chaos synchronization phenomenon, SPICE simulations were perfomed regarding to mutually-coupled cell circuits which consists of 2 cell circuits. The dynamics of the CNN for the chaos synchronization phenomenon is given by

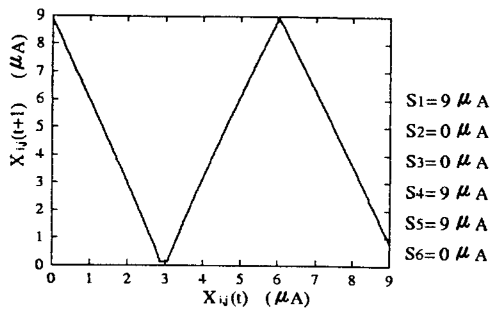
$$X_{1,1}(t+1) = (\sum_{n=1}^{6} {}^{1,1}S_n\, {}^{1,1}W_n + \sum_{n=1}^{6} {}^{1,2}S_n\, {}^{1,2}W_n)/2C,$$

$$X_{1,2}(t+1) = (\sum_{n=1}^{6} {}^{1,2}S_n\, {}^{1,2}W_n + \sum_{n=1}^{6} {}^{1,1}S_n\, {}^{1,1}W_n)/2C, \quad (7)$$

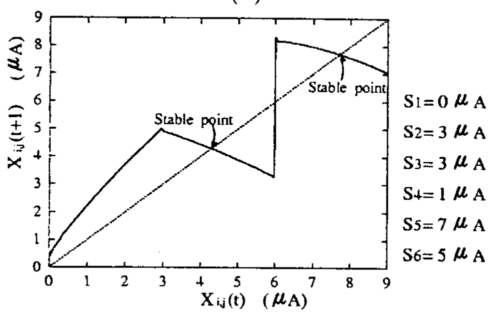
where C was set to $C = 9\mu A$. The SI cell circuits were connected via terminal Q (see in Fig.4). In the SPICE simulations, the current sources I_S's which correspond to the values of the singletons were set to the same values used in the SPICE simulation of Fig.7. Figure 8 shows the output signals of the mutually-coupled cell circuits. In the SPICE simulations of Fig.8, the initial values of the 1st and 2nd cells were set to $X_{1,1}(0) = 1\mu A$ and $X_{1,2}(0) = 2\mu A$, respectively. From Fig.8, the proposed CNN is useful as an experimental tool for chaos synchronization system.

Table 1. Current values for the membership functions

Building Block	Current Sources
MFC-1	$I_{n1} = 8.8\mu A$
MFC-2	$I_{pz1} = 2.9\mu A,\ I_{pz2} = 0\mu A$
MFC-3	$I_{nz1} = 3.2\mu A,\ I_{nz2} = 17.8\mu A$
MFC-4	$I_{pz1} = 5.9\mu A,\ I_{pz2} = 9.7\mu A$
MFC-5	$I_{nz1} = 6.3\mu A,\ I_{nz2} = 27.0\mu A$
MFC-6	$I_{p1} = 19.3\mu A$



(a)



(b)

Fig.7 Nonlinear function of the proposed cell circuit.

4.3 Traveling Wave

To observe the traveling wave phenomenon, SPICE simulations were performed regarding to a chain of 10 SI cell circuits. Figure 9 shows the circuit architecture of the CNN to observe the traveling wave phenomenon. The dynamics of the proposed CNN in Fig.9 is given by

$$X_{i,j}(t+1) = (\sum_{n=1}^{6} {}^{i,j}S_n\, {}^{i,j}W_n)/C + D_{i-1,j}(\sum_{n=1}^{6} {}^{i-1,j}S_n\, {}^{i-1,j}W_n)/C$$

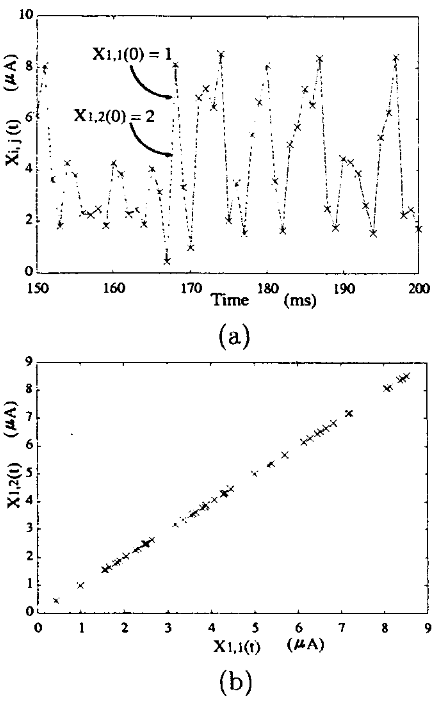


Fig.8 Chaos synchronization phenomenon obtained by SPICE simulation. (a) Output signals of the cell circuits. (b) Phase plot of the output signals of the proposed CNN.

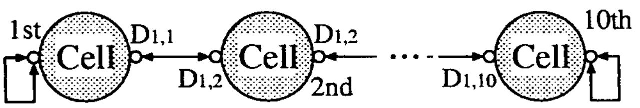


Fig.9 Architecture of the proposed CNN for traveling wave phenomenon.

$$+ \quad \mathrm{D}_{i+1,j}(\sum_{n=1}^{6} {}^{i+1,j}S_n \; {}^{i+1,j}W_n)/\mathrm{C},$$

where C was set to C = $9\mu A$. In the SPICE simulations for traveling wave phenomenon, the singletons of the SI cell circuits were set to $\mathrm{I_{S1}}(={}^{i,j}\,S_1) = 2\mu A$, $\mathrm{I_{S2}}(={}^{i,j}\,S_2) = 0\mu A$, $\mathrm{I_{S3}}(={}^{i,j}\,S_3) = 4\mu A$, $\mathrm{I_{S4}}(={}^{i,j}\,S_4) = 3\mu A$, $\mathrm{I_{S5}}(={}^{i,j}\,S_5) = 3\mu A$, and $\mathrm{I_{S6}}(={}^{i,j}\,S_6) = 2\mu A$. The SI cell used in this SPICE simulation has two stable points, P_r $(r = 1, 2)$. The basin of these stable points, $\mathrm{B}(\mathrm{P}_r)$, is given by $\mathrm{B}(\mathrm{P}_1) = (0\mu A, 3\mu A)$ and $\mathrm{B}(\mathrm{P}_2) = [3\mu A, 9\mu A)$, where $\mathrm{P}_1 = 1.2\mu A$ and $\mathrm{P}_2 = 5.4\mu A$. Figure 10 shows the traveling wave in a chain of 10 SI cell circuits. In the SPICE simulation of Fig.10, the initial state of the 1st cell was set to P_2 and the initial states of all the other cells were set to P_1. In Fig.10, the parameters $\mathrm{D}_{i,j}$'s were set to 1/5. Figure 11 shows the states of the SI cell circuits obtained by the SPICE simulations. From Figs.10 and 11, the traveling wave has propagated to the 10th cell after 12 *ms*.

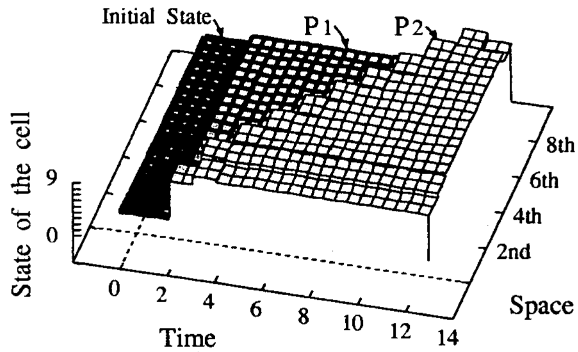


Fig.10 Simulated traveling wave in a chain of 10 cell circuits.

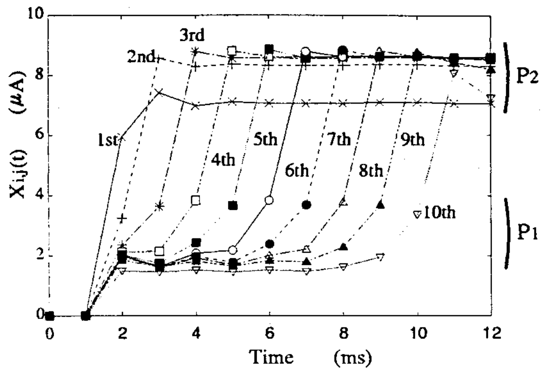


Fig.11 States of the cell circuits obtained by SPICE simulation.

5 Conclusion

A discrete-time CNN using 1-dimensional chaos circuits with controllable nonlinear functions has been proposed in this paper.

The SPICE simulations concerning the proposed CNN showed the following results: 1. Thanks to the flexibility of the nonlinear functions, the dynamics of the proposed CNN can be controlled electronically. 2. The proposed CNN can demonstrate the chaos synchronization phenomenon as well as the traveling wave phenomenon. The proposed CNN is integrable by a standard BiCMOS technology.

References

[1] V.P.Muñuzuri, V.P.Villar, and L.O.Chua, "Autowaves for image processing on a two-dimensional CNN array of excitable nonlinear circuits: flat and wrinkled labyrinths," IEEE Trans. Circuits & Syst.-I, vol.40, no.3, pp.174-181, Mar. 1993.

[2] L.Pivka, "Autowaves and spatio-temporal chaos in CNNs-part I: a tutorial," IEEE Trans. Circuits & Syst., vol.42, no.10, pp.638-649, Oct. 1995.