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Analysis of Two-Dimensional Conductive Plates Based on CNNs

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1. Introduction

Recently, there have been many papers on the analysis of transmission lines, because they are becoming more important for designing VLSI chips as the operation speed of the chips becomes higher. On the other hand, a device simulation is also very important to design Integrated Circuits (ICs) and to understand the qualitative behavior. The methods for analyzing conductive plates have been proposed. For semiconductor devices, the circuit equations are described by partial differential equations and are usually solved by the finite element techniques. The linearization of the semiconductor equations are efficient solution for their transient and steady-state [1-2]. As applications for the resistance calculations, two basic methods have been proposed. One of them is based on a boundary element method [3], and the other is a finite element method [4]. These methods are really time-consuming, because, to obtain exact solutions, the device must be divided into many small sections.

Since the middle of last decade, Cellular Neural Networks (CNNs) have been noted in the fields of circuits and systems [5-6]. The CNN is an array of fundamental elements, called cell. Neighbor cells are coupled each other directly, while distant cells are connected with propagation effects. One paradigm of CNN applications has been proposed as an implementation of solving Partial Differential Equations (PDEs) and systems of Ordinary Differential Equations (ODEs) [7-8]. Therefore, CNN has been adopted to simulate various nonlinear spatio-temporal phenomena such as traveling waves, autowaves, spiral waves and so on [9].

In this study, we propose an analysis method of potential propagation in conductive plates based on two-layer CNN. The computer simulated results show that the two-layer CNN can simulate the potential propagation in conductive plates for various sets of circuit parameters.

2. Two–Dimensional Circuits

We consider a conductive plate. In order to analyze the potential propagation of the conductive plate, we discretize the plate spatially and propose two-dimensional circuits as discretized model shown in Fig. 1 [10]. The discrete steps are

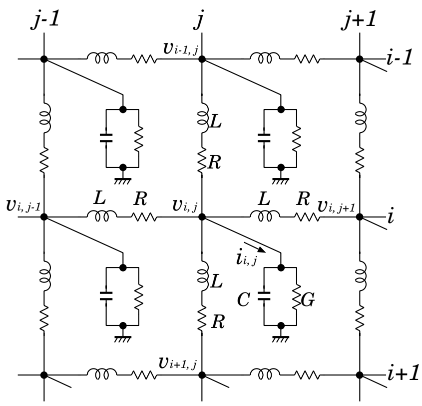

Figure 1: Discretized model.

equidistance in both directions. Hence, the circuit parameters R and L are the same value in both directions.

We assume the model as the lumped constant circuit, hence, the state equations of the discretized model are described by the following ordinary differential equations.

$$\begin{aligned} \frac{dv_{i,j}}{dt} &= -\frac{G}{C}v_{i,j} + \frac{1}{C}i_{i,j} \\ \frac{di_{i,j}}{dt} &= -\frac{R}{L}i_{i,j} + \frac{1}{L}(v_{i-1,j} + v_{i+1,j} \\ &\quad +v_{i,j-1} + v_{i,j+1} - 4v_{i,j}). \end{aligned} \tag{1}$$

After the normalization of time:

$$\tau = \frac{1}{\sqrt{LC}}t, \tag{2}$$

we have

$$\begin{aligned} \frac{dv_{i,j}}{d\tau} &= -G\sqrt{\frac{L}{C}}v_{i,j} + \sqrt{\frac{L}{C}}i_{i,j} \\ \frac{di_{i,j}}{d\tau} &= -R\sqrt{\frac{C}{L}}i_{i,j} + \sqrt{\frac{C}{L}}(v_{i-1,j} + v_{i+1,j} \\ &\quad +v_{i,j-1} + v_{i,j+1} - 4v_{i,j}). \end{aligned} \tag{3}$$

3. Two-Layer Cellular Neural Networks

Cellular Neural Network has given rise to wide interests in theoretical researches for various generalizations and their applications in the areas like as image processing, pattern recognition, motion detection, and computer vision as solving various types of nonlinear differential equations. In our previous researches, we have reported various applications using two-layer CNNs. In the two-layer CNN, the connection between the first layer and the second layer is given by the C template.

The state equations and output equations of the two-layer CNN are described as follows:
[State Equations]

$$\begin{aligned}\frac{dv_{x1ij}(t)}{dt} =& -v_{x1ij}(t) + \sum_{C(k,l)\in N_r(i,j)} A_1(i,j;k,l)v_{y1kl}(t)\\ &+ \sum_{C(k,l)\in N_r(i,j)} B_1(i,j;k,l)v_{u1kl}(t)\\ &+ \sum_{C(k,l)\in N_r(i,j)} C_1(i,j;k,l)v_{y2kl}(t) + I_1\\ \frac{dv_{x2ij}(t)}{dt} =& -v_{x2ij}(t) + \sum_{C(k,l)\in N_r(i,j)} A_2(i,j;k,l)v_{y2kl}(t)\\ &+ \sum_{C(k,l)\in N_r(i,j)} B_2(i,j;k,l)v_{u2kl}(t)\\ &+ \sum_{C(k,l)\in N_r(i,j)} C_2(i,j;k,l)v_{y1kl}(t) + I_2.\end{aligned} \tag{4}$$

[Output Equations]

$$\begin{aligned}v_{y1ij}(t) &= \frac{1}{2}(|v_{x1ij}(t)+1| - |v_{x1ij}(t)-1|)\\ v_{y2ij}(t) &= \frac{1}{2}(|v_{x2ij}(t)+1| - |v_{x2ij}(t)-1|).\end{aligned} \tag{5}$$

The cloning templates connecting cells are given as follows:

$$\begin{aligned}\boldsymbol{A}_m &= \begin{pmatrix} A_{i-1,j-1} & A_{i-1,j} & A_{i-1.j+1}\\ A_{i,j-1} & A_{i,j} & A_{i,j+1}\\ A_{i+1,j-1} & A_{i+1,j} & A_{i+1,j+1}\end{pmatrix}\\ \boldsymbol{B}_m &= \begin{pmatrix} B_{i-1,j-1} & B_{i-1,j} & B_{i-1.j+1}\\ B_{i,j-1} & B_{i,j} & B_{i,j+1}\\ B_{i+1,j-1} & B_{i+1,j} & B_{i+1,j+1}\end{pmatrix}\\ \boldsymbol{C}_m &= \begin{pmatrix} C_{i-1,j-1} & C_{i-1,j} & C_{i-1.j+1}\\ C_{i,j-1} & C_{i,j} & C_{i,j+1}\\ C_{i+1,j-1} & C_{i+1,j} & C_{i+1,j+1}\end{pmatrix}\\ I_m &= c\end{aligned} \tag{6}$$

where $m = 1,2$ and c is a constant. $\boldsymbol{A}_m$, $\boldsymbol{B}_m$, and $\boldsymbol{C}_m$ are feedback templates, control templates, and coupling templates, respectively. These templates define the behavior of the two-layer CNNs with input and initial states.

4. Simulation Results

Between the two equations (3) and (4), we can see remarkable similarity. Both of them are systems of locally interconnected ordinary differential equations. By comparing them, it is easy to design the cloning templates of the two-layer CNN describing the two-dimensional circuits as follows:

$$\boldsymbol{A}_1 = \begin{pmatrix} 0 & 0 & 0\\ 0 & 1-G\sqrt{\frac{L}{C}} & 0\\ 0 & 0 & 0\end{pmatrix}, \quad \boldsymbol{C}_1 = \begin{pmatrix} 0 & 0 & 0\\ 0 & \sqrt{\frac{L}{C}} & 0\\ 0 & 0 & 0\end{pmatrix},$$
$$\boldsymbol{B}_1 = \boldsymbol{0}, \qquad I_1 = 0. \tag{7}$$

$$\boldsymbol{A}_2 = \begin{pmatrix} 0 & 0 & 0\\ 0 & 1-R\sqrt{\frac{C}{L}} & 0\\ 0 & 0 & 0\end{pmatrix}, \quad \boldsymbol{C}_2 = \begin{pmatrix} 0 & \sqrt{\frac{C}{L}} & 0\\ \sqrt{\frac{C}{L}} & -4\sqrt{\frac{C}{L}} & \sqrt{\frac{C}{L}}\\ 0 & \sqrt{\frac{C}{L}} & 0\end{pmatrix},$$
$$\boldsymbol{B}_2 = \boldsymbol{0}, \qquad I_2 = 0. \tag{8}$$

As illustrated examples, we simulated the two-impulse responses on the uniform plate for two different circuit parameters. One is damped oscillation case, and the other is ideal lossless case for the same initial condition. The initial state is shown in Fig. 2, where i and j mean discretized spaces, and v means the voltage. Namely, the plate is analyzed by the two-layer CNN with 100×100 cells.

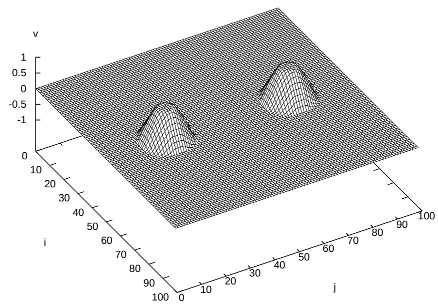

Figure 2: Initial state.

4.1. Damped Oscillation

First, we simulate the potential propagation of the plate for the case of damped oscillation. We used the following templates:

$$\boldsymbol{A}_1 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0.9 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \boldsymbol{C}_1 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 10 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \\ \boldsymbol{B}_1 = \boldsymbol{0} \qquad I_1 = 0. \tag{9}$$

$$\boldsymbol{A}_2 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0.999 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \boldsymbol{C}_2 = \begin{pmatrix} 0 & 0.1 & 0 \\ 0.1 & -0.4 & 0.1 \\ 0 & 0.1 & 0 \end{pmatrix}, \\ \boldsymbol{B}_2 = \boldsymbol{0} \qquad I_2 = 0. \tag{10}$$

Transient responses are shown in Fig. 3. We observe that the potential propagation is damped down as time goes. Note that the scale of the voltage is quite small for (c).

4.2. Ideal Lossless Oscillation

Next, we consider the ideal lossless plate. The inductance L and the capacitance C of the plate are the same values as the damped case, but the resistance R and the conductance G are set to be zero, respectively. The cloning templates for this case are given as follows:

$$\boldsymbol{A}_1 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \boldsymbol{C}_1 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 10 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \\ \boldsymbol{B}_1 = \boldsymbol{0}, \qquad I_1 = 0. \tag{11}$$

$$\boldsymbol{A}_2 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \boldsymbol{C}_2 = \begin{pmatrix} 0 & 0.1 & 0 \\ 0.1 & -0.4 & 0.1 \\ 0 & 0.1 & 0 \end{pmatrix}, \\ \boldsymbol{B}_2 = \boldsymbol{0}, \qquad I_2 = 0. \tag{12}$$

The transient responses are shown in Fig. 4. We can observe that the oscillation does not damped down. Note that the scales of the voltages are the same for (a), (b) and (c).

5. Conclusions

In this study, it has been shown that the two-dimensional conductive plates can be solved by the framework of the two-layer CNNs. After discretizing the plate into two-dimensional circuits, the ODEs describing the circuit was related with the two-layer CNN equations. By using the relation, the cloning templates of the two-layer CNN were obtained. The computer simulated results showed that the two-layer CNN could simulate the potential propagation in conductive plates for various sets of circuit parameters.

Our future research is how to modify the cloning templates when some obstacles are put on the conductive plates.

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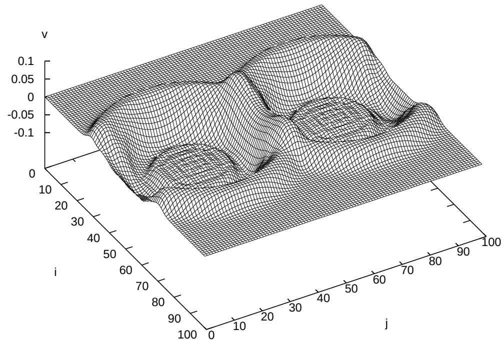
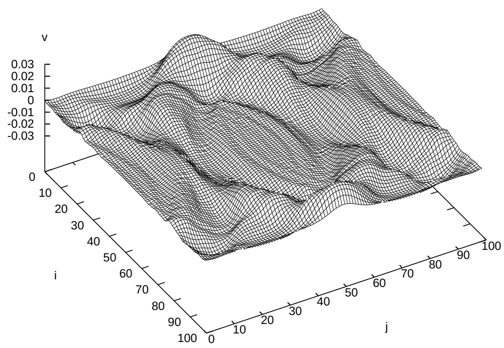
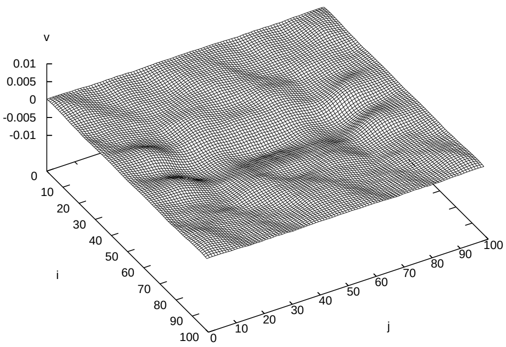


(a) $\tau = 25$

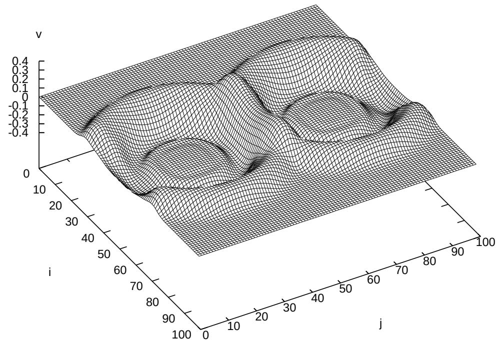


(b) $\tau = 50$

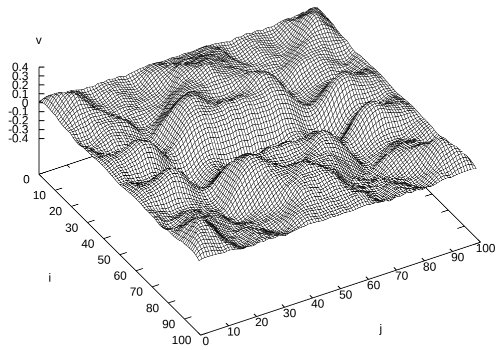


(c) $\tau = 100$

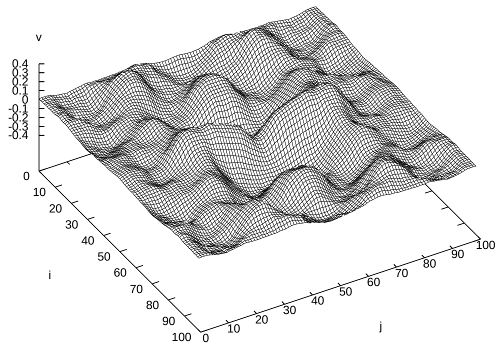
Figure 3: Potential propagation (damped oscillation).



(a) $\tau = 25$



(b) $\tau = 100$



(c) $\tau = 200$

Figure 4: Potential propagation (ideal lossless oscillation).