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Clustering Phenomena in Coupled Chaotic Circuits Located in 3-Dimensional Space

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1. Introduction

Many studies are proposed to utilize synchronization phenomena for clustering. Previously, discrete-time models have often been used in these studies, however analysis of using circuit models in continuous-time has not been well studied.

In this study, we focus on synchronization phenomena when the chaotic circuits are located in 3-dimensional space.

2. System Model

The chaotic circuit model is shown in Fig. 1. This circuit consists of a negative resistor, an inductor, two capacitors and dual-directional diodes.

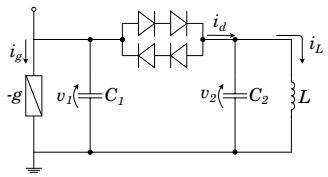

Figure 1: Circuit model.

3. Simulation Results

In this study, we investigate synchronization phenomena and clustering phenomena of chaotic circuits located at 3-dimensional space. Table 1 shows the locations of the chaotic circuits. All circuits are connected each other by resistors.

Table 1: The location of chaotic circuits.

location	x	y	z	location	x	y	z
1	0.15	0.05	0.15	16	0.80	0.20	0.15
2	0.20	0.25	0.30	17	0.85	0.15	0.05
3	0.35	0.35	0.25	18	0.70	0.60	0.95
4	0.25	0.25	0.05	19	0.90	0.80	0.85
5	0.30	0.15	0.05	20	0.80	0.95	0.75
6	0.05	0.20	0.10	21	0.75	0.85	0.70
7	0.15	0.30	0.15	22	0.85	0.80	0.85
8	0.05	0.05	0.25	23	0.60	0.60	0.60
9	0.20	0.05	0.35	24	0.80	0.65	0.90
10	0.25	0.10	0.20	25	0.65	0.80	0.80
11	0.35	0.05	0.25	26	0.65	0.65	0.85
12	0.25	0.05	0.35	27	0.95	0.95	0.95
13	0.75	0.15	0.25	28	0.90	0.65	0.75
14	0.95	0.30	0.35	29	0.70	0.85	0.65
15	0.80	0.15	0.10	30	0.75	0.80	0.85

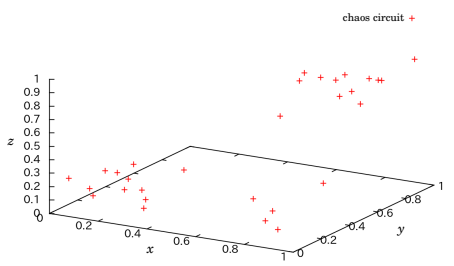

Figure 2: Chaotic circuits location of 3-dimensional space.

The normalized circuit equations of the circuit equations by this coupled chaotic circuits are given as follows:

$$\begin{cases} \dfrac{dx_i}{d\tau} = z_i \\ \dfrac{dy_i}{d\tau} = \alpha\gamma y_i - \alpha\beta f - \alpha \displaystyle\sum_{i,j=1}^{N} r_{i,j}(y_i - y_j) \\ \dfrac{dz_i}{d\tau} = \beta f - x_i. \end{cases} \tag{1}$$

The circuit parameters are chosen as $\alpha = 0.50$, $\beta = 20.00$ and $\gamma = 0.50$. The nonlinear function f corresponds to the $i - v$ characteristics of the nonlinear resistors consisting of the diodes and are given as follows:

$$f = \begin{cases} y_i - z_i - 1 & (y_i - z_i > 1) \\ 0 & (|y_i - z_i| \leq 1) \\ y_i - z_i + 1 & (y_i - z_i < 1). \end{cases} \tag{2}$$

where, i in the equation represents the circuit itself, and j is the coupling with other circuits. The parameter r represents the coupling strength between the circuits. In this simulation, we set the coupling parameter value $r_{i,j}$ to correspond the distance between the circuits by the following equation:

$$r_{i,j} = \frac{q}{(d_{i,j})^2}. \tag{3}$$

$d_{i,j}$ represents the Euclidean distance between the $i-th$ and the $j-th$ circuits. Futher, the parameter q is the weight parameter that determines the coupling strengths. In this case, we set parameter $q = 0.004724$.

Figure 2 shows the computer simulation results.

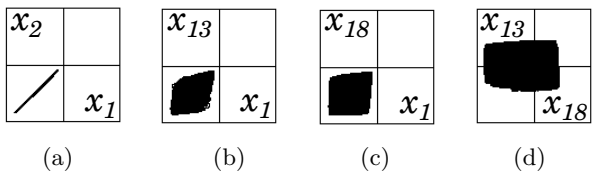

Figure 3: Simulation results.

In this result, we have confirmed clustering phenomena. It can be categorized 3 clusters: the first cluster is circuit-1 to circuit-12, the second cluster is circuit-13 to circuit-17 and the third cluster is circuit-18 to circuit-30. From these results, we confirm to be synchronized at in-phase state in the cluster. However, we could not confirm to be synchronized between clusters.

4. Conclusion

In this study, we investigated synchronization phenomena when the chaotic circuits are located in 3-dimensional space. In these results, it was confirmed that the chaotic circuits were different from synchronization phenomena by distance information and the clustering phenomena were observed.