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Study on Reservoir Computing Combining Chaotic Circuits and Periodic Oscillators

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Abstract— **Reservoir computing is suitable for fast machine learning and consists of a reservoir layer and a readout layer. In previous studies, the reservoir layer consists of nodes replaced by van der Pal oscillators. In this study, the reservoir layer is composed of a van der Pal oscillator and a chaos circuit. Using this, the input waveform generation task is performed, the error between the input and generated waveforms is calculated, and the model is evaluated.**

Keywords; oscillator, chaotic circuits, Reservoir Computing

I. INTRODUCTION

Deep learning, which has attracted much attention in recent years, is a type of machine learning based on population neural network models. However, problems such as computational cost in learning exist. Therefore, reservoir computing has been proposed as a model that aims for sufficiently high computational performance while reducing the amount of computation required for learning [1]. In reservoir computing, the composite weights of the input and reservoir layers are fixed, and only the output weights are used for learning. This allows for a reduction in computational cost. In this study, we implement physical reservoir computing in which nodes are replaced by oscillators and chaotic circuits and evaluate the waveform generation task in reservoir computing.

II. PROPOSED MODEL

Figure 1 shows a model diagram of reservoir computing used in this study. The nodes of the reservoir layer are replaced by van der pol oscillators and chaotic circuits, which are composed of a combination of them. In this case, the input waveform generation task for reservoir computing was performed, and sin waves were input to the input layer. The proposed model was evaluated by comparing the input sin wave with the sin wave generated in the output layer and determining the error.

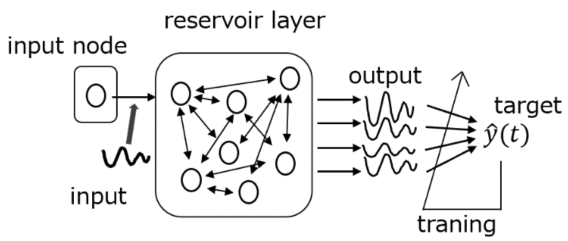

Figure1. Structure of proposed reservoir computing.

Figure 2 shows the structure of van der pol oscillator.

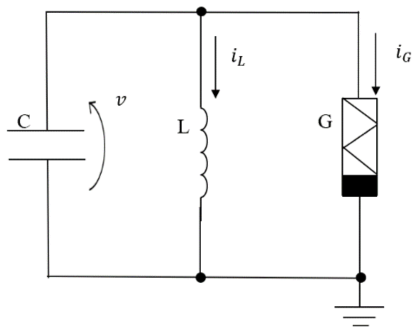

Figure 2. Circuit model of van der pol oscillator.

i_L represents the current flowing through the inductor. i_G represents the current flowing through the nonlinear resistance. v represents the voltage across the capacitance. Equation (1) shows the circuit equation for the van der pol oscillator.

$$\begin{cases} C\frac{dv_n}{dt} = -i_L - i_G - \frac{1}{R}\sum_{k=1}^{N}(v_k - v_n) \\ L\frac{di_n}{dt} = v_n \end{cases} \quad (1)$$

Equation (2) is the normalized form of this circuit equation.

$$\begin{cases} \frac{dx_n}{d\tau} = \varepsilon x_n(1 - x_n^2) - y_n - \sum_{n,k=1}^{N} K_{nk}(x_k - x_n) \\ \frac{dy_n}{d\tau} = x_n \end{cases} \quad (2)$$

The normalization parameters are shown below.

$$v = \sqrt{\frac{g_1}{g_3}}x, i = \sqrt{\frac{g_1 C}{g_2 L}}y, t = \sqrt{LC}\tau, \varepsilon = g_1\sqrt{LC}, \gamma_{nk} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

N is the number of van der pol oscillators in reservoir layer, and K_{nk} is the coupling strength. Equation (3) shows the K_{nk}.

$$K_{nk} = E_{nk}\gamma_{nk} \quad (3)$$

E_{nk} is the adjacency matrix of network.

Figure 3 then shows the Nishio-Inaba circuit [2], the chaotic circuit used in this study.

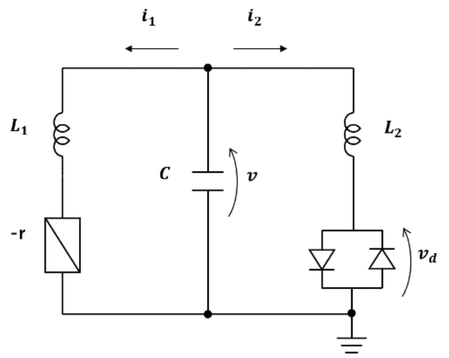

Figure 3. Circuit model of chaotic circuit.

Equation (4) shows the circuit equation for the Nishio-Inaba circuit.

$$\begin{cases} L_1 \frac{di_1}{dt} = v + ri_1 \\ L_2 \frac{di_2}{dt} = v - v_d \\ C \frac{dv}{dt} = -i_1 - i_2 \end{cases} \tag{4}$$

Equation (5) shows the normalized equation of the circuit equation for the Nishio-Inaba circuit. Equation (6) shows for $f(y_i)$ included in the normalization equation.

$$\begin{cases} \dot{x}_i = \alpha x_i + z_i \\ \dot{y}_i = z_i - f(y_i) \\ \dot{z}_i = -x_i - \beta y_i - \sum_{i,j=0}^{n} \gamma_{i,j}(zi - zj) \end{cases} \tag{5}$$

$$f(y_i) = \frac{\delta}{2}\left(\left|y_i + \frac{1}{\delta}\right| - \left|y_i - \frac{1}{\delta}\right|\right) \tag{6}$$

The normalization parameters are shown below.

$$i_1 = \sqrt{\frac{C}{L_1}} V x_n, i_2 = \frac{\sqrt{L_1 C}}{L_2} V y_n, v = V z_n, \alpha = r\sqrt{\frac{C}{L_1}}, \beta = \frac{L_1}{L_2}$$

$$\delta = r_d \frac{\sqrt{L_1 C}}{L_2}, \gamma_{ij} = \frac{1}{R}, t = \sqrt{L_1 C}\tau$$

III. Simulation Result

One node in the input layer was replaced by a van der pol oscillator. The number of nodes in the reservoir layer was set to 20; the parameter $\varepsilon = 0.3$ for the van der pol oscillator and the parameters $\beta = 3.0$, $\delta = 470$, $\alpha = 0.46$, and $\gamma_{i,j} = 0.01$ for the Nishio-Inaba circuit were fixed. The connection probability was set to 1 and all couplings for both circuits, and the coupling strength of the nodes between the reservoir layers was fixed at K=0.05.

Figure 4 shows the error in the waveform generation task when the number of van der pol oscillators and chaotic circuits in the reservoir layer is varied.

The NRMSE method was used in this study to determine the error. Equation (7) shows the formula for NRMSE.

$$NRMSE = \frac{\sqrt{\frac{1}{T}\sum_{n=1}^{T} ||d(n) - \hat{y}(n)||_2^2}}{\frac{1}{T}\sum_{n=1}^{T} ||d(n) - \bar{d}(n)||_2^2} \tag{7}$$

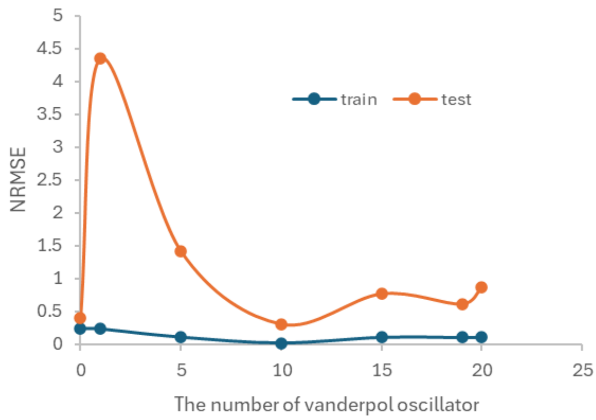

Figure 4. Error in waveform generation task.

The figure shows that the error was smallest when the number of oscillators and chaos circuits were 10 and 10, respectively. The error exceeded 1 when the number of chaos circuits was 15 and 19.

IV. Conclusion

In this study we evaluated the waveform generation task when the nodes that make up the reservoir layer were replaced by chaotic circuits and van der Pol oscillators. The results showed that the error was the smallest when the same number of chaotic circuits and van der Pol oscillators were used. In the future, we would like to verify whether the same phenomenon occurs when the number of nodes is increased.

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