International Joint INNS-IEEE Conference on Neural Networks (IJCNN'2001), Washington DC, USA (July 14-19, 2001).

Analog CMOS Implementation of Diffusive Lotka-Volterra Neural Networks

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Purpose

Analog integrated circuits that implement oscillatory neural systems are very important tools for exploring and discovering novel forms of neural information processing. However, there are severe difficulties in constructing compact circuits with low-power dissipation, which prevents large-scale integration of oscillatory neural circuits. In this report, aiming at the development of oscillatory neural VLSIs, we present novel CMOS circuits that implement the Lotka-Volterra (LV) oscillatory systems.

Novel aspects of work

The present oscillatory neural circuit has the following merits:

i) The unit circuit consists of only six MOS transistors.
ii) All the transistors operate in their subthreshold region, which ensures micropower operations of the circuit.
iii) The underlying mechanism for the oscillation is both qualitatively and quantitatively known.
iv) The stability of the circuit can be controlled by external inputs.

These aspects make it easier to design neural VLSIs suitable for a particular application.

Method

The proposed circuit is directly derived from the LV equation[1]. Applying logarithmic conversion of system variables, the LV equation is transformed to forms of linear combinations of exponential functions. The form is very suitable for current-mode subthreshold CMOS implementation[2].

To implement the LV networks, we employed diffusive LV systems[3]. The system can be constructed by the LV circuit and diffusive devices. Each variable node is coupled with neighboring circuits through the diffusive device.

Results

We fabricated the LV circuit using standard CMOS technology (feature size: 5 um). The circuit exhibited stable refractory oscillation. The limit-cycle trajectory was independent from initial conditions. The resultant mean-power dissipation was O(10^-8) W.

Then, we investigated behaviors of the diffusive LV circuit using the fabricated circuits and single MOS transistor as the oscillator and the diffusive device, respetively. In the case of self-variable coupling, all the circuits were synchronized each other without any phase difference, while the circuits were synchronized with phase differences of pi when cross-variable coupling was used, as expected.

Conclusions

A compact and micropower CMOS circuit was proposed for developing analog VLSIs that implement large-scale oscillator networks. The circuit was derived from the LV equation with a novel variable-conversion technique, and exhibited subthreshold refractory oscillations. Experimental results of a prototype chip agreed well with theoretical predictions, which indicates that large-scale oscillatory systems consisting of the proposed circuits can be easily implemented in analog LSIs using standard CMOS technology.

References

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