Image Object Extraction using Resistive-Fuse and Oscillator Networks and a Pulse-Modulation Circuit for their LSI Implementation

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1. Introduction

In order to recognize a natural scene image, which usually includes several objects, we should segment the image into several recognition target objects and extract them one by one. In this paper, we propose a new object extraction method using a resistive-fuse network and an oscillator network [1, 2].

In order to achieve real-time image recognition, VLSI implementation of object extraction is essential. We also propose a pulse modulation circuit for implementing the resistive-fuse/oscillator networks. This circuit utilizes conversion from a pulse modulation signal to a voltage [3] for realizing nonlinear analog dynamics of both networks.

2. A new object extraction method for natural scene recognition

The segmentation process only using oscillator networks cannot achieve object extraction because an image is segmented into too small pieces. Although resistive-fuse networks can achieve flexible segmentation depending on an object size, the networks cannot extract each segmented region automatically. Thus, we propose a new method by combining both networks.

Discrete-time dynamics of resistive-fuse networks is expressed as follows: $O_i(t+1) = O_i(t) - \nu[\sum_{k\in n_i} G(O_i - O_k) + \sigma(O_i - I_i)]$, where I_i and O_i represent an input and output of pixel i, respectively: n_i is the neighborhood of i: ν and σ are constant parameters. $G(\cdot)$ is a voltage-current characteristic of a resistive-fuse, as shown in Fig. 1. By changing the parameter η (See Fig. 1(b)), one can avoid reaching local minima, and segment an image into target objects.

The nonlinear oscillator network model that we have already proposed is shown in Fig. 2. The dynamics of an oscillator is expressed by variables x_i and y_i, and includes cubic and hyperbolic-tangent functions of x_i. This dynamics produces periodic behavior of a single oscillator as shown in Fig. 2(b), and synchronous/asynchronous firing states between oscillators as shown in Fig. 2(c). A region firing synchronously is extracted as an object region.

We confirmed object extraction of a real image by numerical simulation. Original and segmented images are shown in Fig 3(a) and (b), respectively. As shown in Fig 3(b), regions corresponding to recognition objects such as human faces are smoothed, and extracted as shown in Fig. 3(c) and (d), where the image shown in Fig. 3(b) is an input of an oscillator network.

3. A pulse modulation circuit for object extraction

A resistive-fuse/oscillator circuit is shown in Fig. 4(a), which is based on the oscillator circuit that we have already proposed [1]. This circuit has two modes: resistive-fuse and oscillator, and the two modes are switched by SEL_1.

In the resistive-fuse mode, the values of O_i and I_i are represented by voltage V_{xi} and V_{yi}, and are held at capacitors C_{xi} and C_{yi}, respectively. Voltage V_{xi} is linearly transformed into a pulse width modulation (PWM) signal PS_1 with a pulse width of T_i by comparator $COMP_{i1}$. The absolute difference value $|O_i - O_k|$ is generated by an XOR gate as a PWM signal PS_4 with a width of T_{ik0}. Another absolute difference value $|O_i - I_i|$ is generated by switching signal SEL_2. The sign of $O_i - O_k$ is obtained by the sign generator. In our pulse modulation circuit architecture, pulse signals and reference voltage waveforms must be synchronous. Therefore, a pulse PS_4 is linearly transformed into a pulse PS_5 with a width of $T_{ik}(= T_{ik0})$. This pulse turns on SW_2 and capacitor C_1 holds the voltage $V_G(T_{ik})$, where V_G varies in the time-domain: $V_G(t) = G(t)$. Voltage $V_G(T_{ik})$ is linearly transformed into a pulse PS_6 with a width of $G(|O_i - O_k|)$. By using the sign signal, charges corresponding to the value $G(O_i - O_k)$ are injected into or extracted from C_{xi} in each time step. Thus, nonlinear transformation $G(\cdot)$ can be obtained by using PWM signals and nonlinear reference voltage waveform $V_G(t)$.

In the oscillator mode, variables x_i and y_i in the dynamics of an oscillator are represented by voltages V_{xi} and V_{yi}. The cubic and hyperbolic-tangent functions are generated by converting from voltages into pulse phase modulation (PPM) signals and switching nonlinearly modulated current sources [1]. The PPM signals switch current sources, and small charges corresponding to finite differences of x_i and y_i are injected into or extracted from C_{xi} and C_{yi} in each time step.

4. Circuit simulation results

We performed circuit simulation (HSPICE) of the proposed circuit. The device parameters used were based on a 0.6μm CMOS process, and the supply voltage was 5.0V. As shown in Fig. 4(c) and (d), the expected resistive-fuse characteristic and oscillation were obtained. Thus, it was confirmed that the proposed circuit precisely implements the dynamics of resistive-fuse and oscillator networks.

5. Conclusion

We proposed a new object extraction method using resistive-fuse/oscillator networks.

Moreover, we proposed a PWM/PPM circuit for this method. This circuit can implement both functions of resistive-fuse and oscillator networks by using the same circuit components.

Acknowledgments

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References

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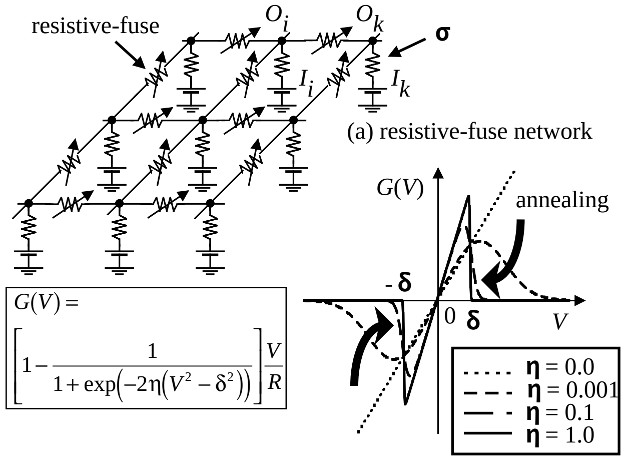
[2] H. Ando, et al., in *ICANN99*, 655-660 (1999)

[3] T. Morie, et al., in *NOLTA'98*, pp. 447–450 (1998)

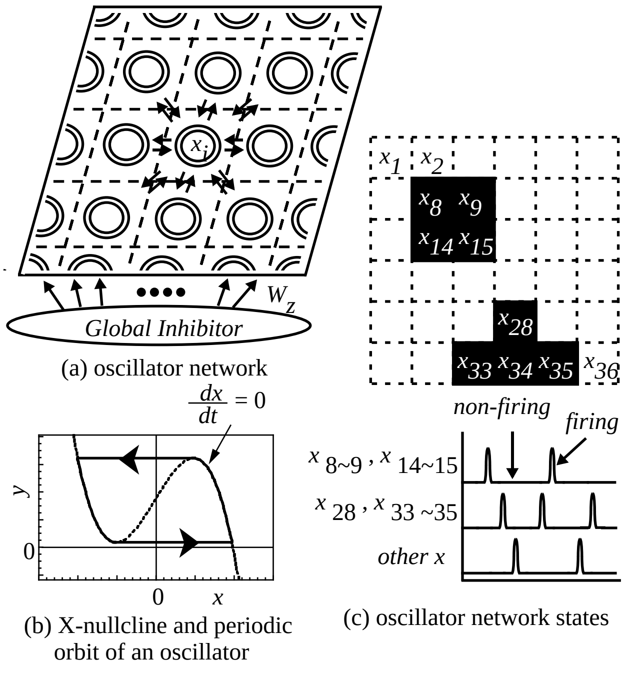


$$G(V) = \left[1 - \frac{1}{1+\exp\left(-2\eta\left(V^2-\delta^2\right)\right)}\right]\frac{V}{R}$$

(a) resistive-fuse network

(b) resistive-fuse characteristic

Figure 1: Resistive-fuse model

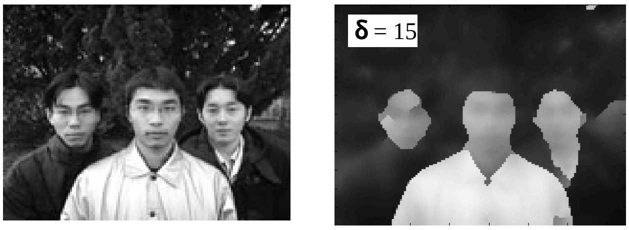


(a) oscillator network

(b) X-nullcline and periodic orbit of an oscillator

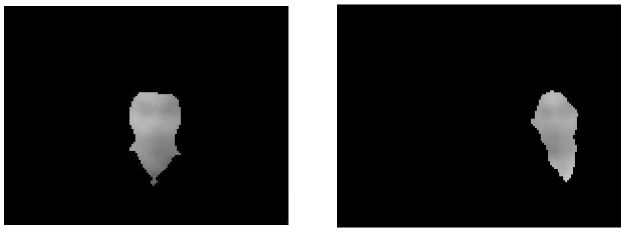
(c) oscillator network states

Figure 2: Oscillator network model



(a) original image (150×120)

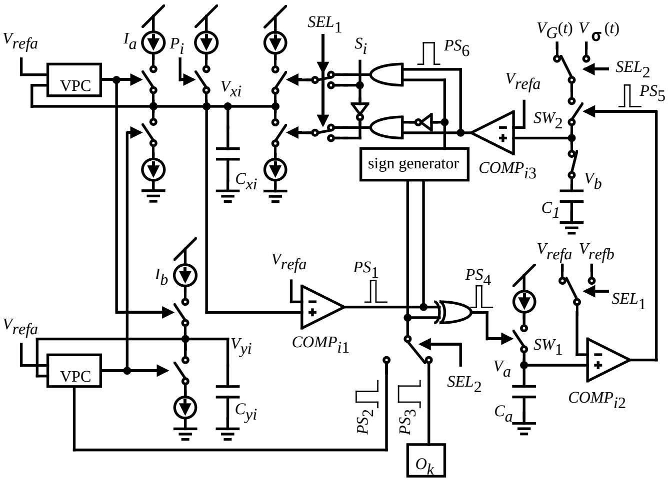
(b) segmented image



(c) extracted image at time t_1

(d) extracted another image at time t_2

Figure 3: Numerical simulation results



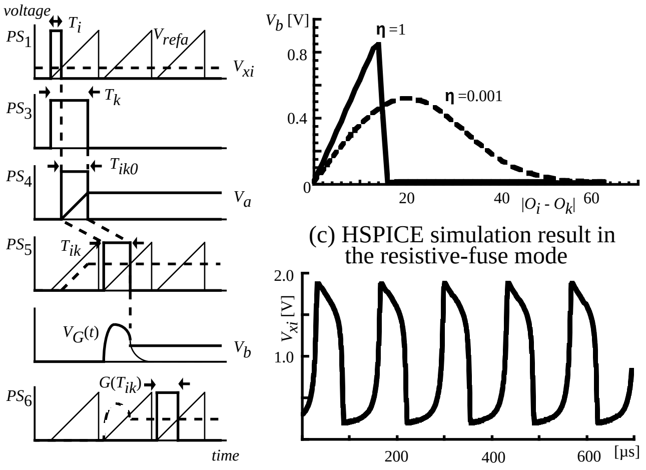
SEL_1 : mode switch

VPC : voltage to PWM/PPM converter

I_a , I_b : nonlinear current sources

S_i , $Vref_b$ are used in the oscillator mode [1].

(a) resistive-fuse/oscillator circuit



(b) resistive-fuse timing chart

(c) HSPICE simulation result in the resistive-fuse mode

(d) HSPICE simulation result in the oscillator mode

Figure 4: Resistive-fuse/oscillator circuit