Image Segmentation/Extraction using Nonlinear Pixel-Parallel Networks and their VLSI Implementation

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1. Introduction

In order to realize intelligent vision systems, we have proposed image processing models using nonlinear pixel-parallel networks inspired by human brain [1]. Flexible image segmentation can be achieved by using the resistive-fuse network that extracts coarse region edges. The object extraction following the segmentation process can be achieved by using the nonlinear oscillator network.

We have also proposed a nonlinear oscillator network circuit based on a merged analog-digital architecture using pulse modulation techniques that implement arbitrary nonlinear discrete-time dynamics [2].

In this paper, we present image segmentation and object extraction using nonlinear pixel-parallel networks. Moreover, we propose an object extraction LSI based on a merged/mixed analog-digital CMOS circuit architecture and demonstrate a basic operation of object extraction processing in an LSI fabricated using a 0.35 μm CMOS technology.

2. Image segmentation and object extraction

Figure 1 shows a schematic circuit diagram of the resistive-fuse network. In this model, each pixel node consists of a voltage source I_i, which corresponds to an input image data at pixel i, and resistor with conductance σ. Each pixel node is connected to the nearest neighbors with the resistive-fuse elements.

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

The nonlinear oscillator network model that we have already proposed [2] 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 synchronous/asynchronous firing states between oscillators as shown in Fig. 2(c). A synchronous firing state is extracted as an object region.

We confirmed image segmentation and object extraction of a real image by numerical simulation. Original and segmented images are shown in Figs. 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 Figs. 3(c) and (d), where the image shown in Fig. 3(b) is an input of an oscillator network.

3. An object extraction LSI using pulse modulation techniques

We designed the proposed nonlinear oscillator network circuit by using a 0.35 μm (2-Poly 3 Metal) CMOS technology. The schematic block diagram of the designed circuit and micro-photograph of the fabricated LSI are shown in Figs. 4 and 5, respectively. The chip area and number of pixels are 9×9 mm^2 and 50×50, respectively, and the power consumption is 300 mW at a power supply voltage of 3.3 V.

The basic operation in the fabricated chip was confirmed with a clock frequency 12.5 MHz lower than a maximum 100 MHz. The input image and schematic of the pixel array area measured are shown in Figs. 6(a) and (b), respectively. The measurement result for object extraction is shown in Fig. 6(c), where all outputs from the three columns in each row are superimposed. First, at t=100μs the oscillator belonging to a pixel in the 18th row fired and this firing state was propagated to neighboring oscillators. Then, all the oscillators belonging to region B were firing synchronously from t=200μs to 670μs. The oscillators belonging to region A were not firing during this period. After all the oscillators belonging to region B reached non-firing state, the oscillator belonging to a pixel in the 8th row started to fire at t=1.9ms. Then, all the oscillators belonging to region A were firing synchronously from t=2.1ms to 2.6ms. As a result, the first and second synchronous oscillating states were extracted as the region B and A, respectively.

4. Conclusion

We proposed a nonlinear oscillator network LSI for object extraction using a merged/mixed analog-digital CMOS circuit architecture with a 0.35 μm CMOS technology. We confirmed the basic region extraction operation by measuring the LSI which can achieve submillisecond operation with the maximum clock frequency.

Acknowledgments

The VLSI chip in this study has been fabricated in the chip fabrication program of VLSI Design and Education Center(VDEC), the University of Tokyo with the collaboration by Rohm Corporation and Toppan Printing Corporation.

References

[1] T. Morie, et al., *NOLTA2001*, pp. 371–374.
[2] H. Ando, et al., *IEICE Trans. Fundamentals.*, vol. E83-A, no. 2, pp. 329–336, 2001.
[3] A. Iwata, et al., *IEICE Trans. Fundamentals.*, vol. E79-A, no. 2, pp. 145–157, 1996.

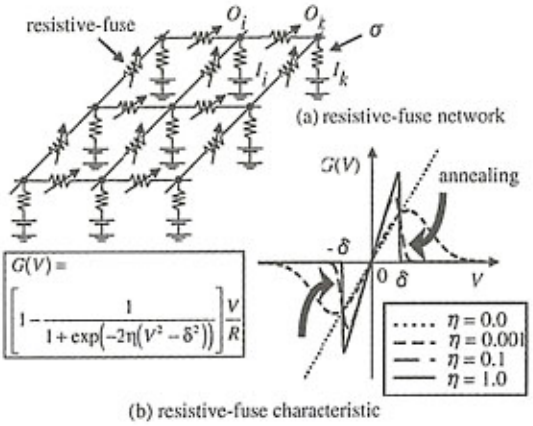

Figure 1: Resistive-fuse network model.

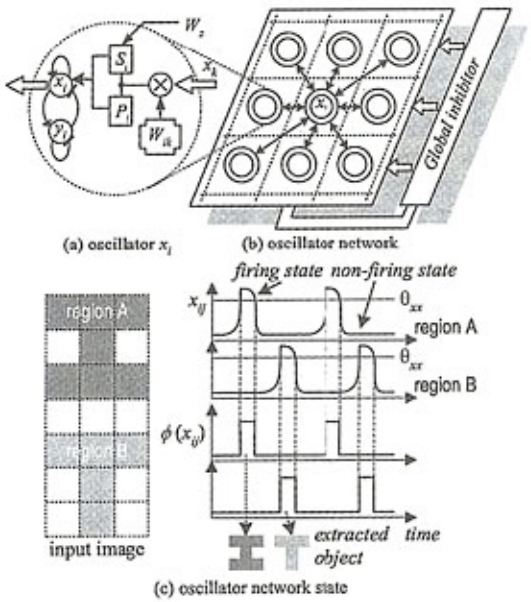

Figure 2: Oscillator network model.

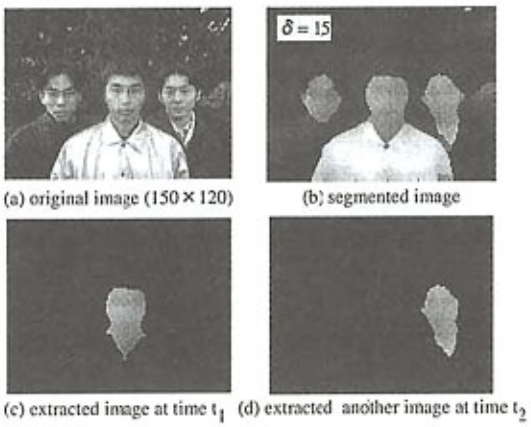

Figure 3: Numerical simulation result.

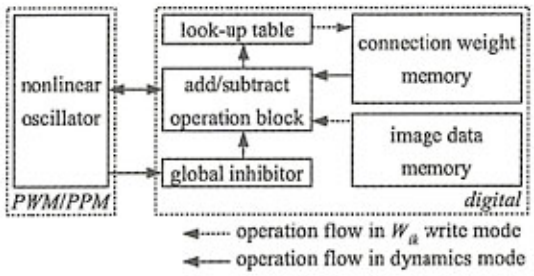

Figure 4: Schematic block diagram of a nonlinear oscillator network circuit.

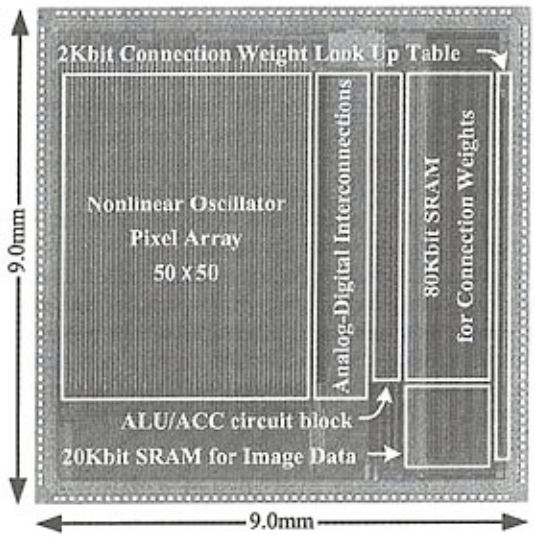

Figure 5: Micro-photograph of the chip.

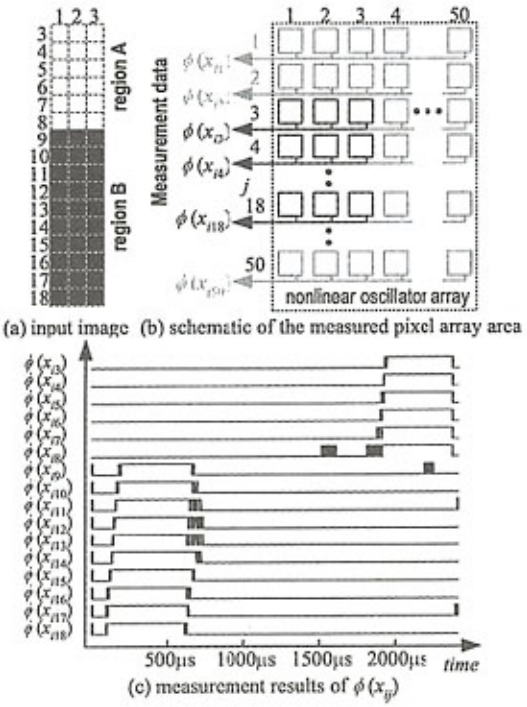

Figure 6: Measurement result.

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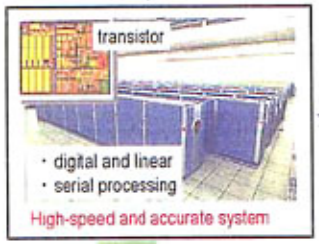
1. Introduction

Computer



High-speed and accurate system

Brain

· analog and nonlinear
· parallel processing

ability of recognition, learning, etc.

Flexible and robust system

New architectures inspired human brain information processing are required for the computers of the next generation

integrated circuit technology → hardware

principle of brain information processing → model

Intelligent information processing system

our research target : recognition of natural scene images

Methods for implementing brain information processing
merged/mixed-signal circuit architecture
· analog, digital and pulse modulation circuit techniques

Information processing models
nonlinear neural networks
· resistive-fuse networks
· nonlinear oscillator networks

2. Image processing techniques for recognizing a natural scene

complicated natural scene image

1. Segmentation into target regions
resistive-fuse networks
2. Individual extraction of segmented regions
nonlinear oscillator networks

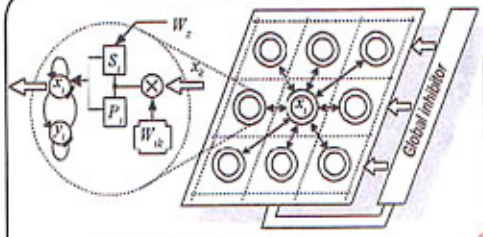
closed white edge boundaries around target regions

3. Feature extraction and pattern matching for each extracted region

tree | background | Mr. A | Mr. B | hand | hand | clothes | background | clothes

A natural scene is recognized by using several processes.

4. Nonlinear oscillator networks for object extraction



Nonlinear oscillator network model

nonlinear oscillator dynamics

$$\frac{dx_i}{dt} = -(x_i - a)(x_i - b)^2 - y_i + P_i + S_i$$

$$\frac{dy_i}{dt} = \varepsilon\left[\gamma\left(1 + \tanh(x_i/\beta)\right) - y_i\right]$$

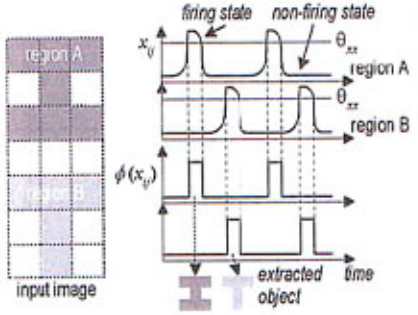
parameters

$$P_i = H\left(\sum_{k\in N_y} W_{ik} - \theta_p\right)$$

$$S_i = H_z\left(\sum_{k\in N_x} W_{ik} H(x_k - \theta_x) - W_z H(z - \theta_{xz})\right)$$

$W_{ik} = I_{max}/(1 + |I_i - I_k|)$ Connection Weight

$z = H(\sum H(x_i - \theta_z) - 1)$ Global inhibitor



Nonlinear oscillator network state

Oscillators belonging to a coherent/different region oscillate synchronously/asynchronously.

Regions oscillating synchronously are extracted as a target region.

image segmentation by using resistive-fuse networks

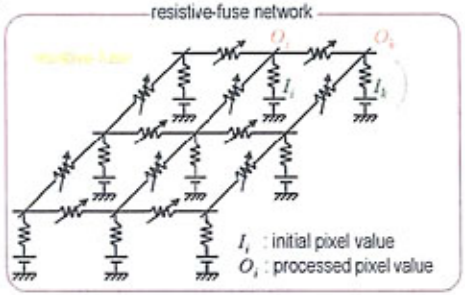
image region extraction by using nonlinear oscillator networks

region A | region B | region C | region D | region E

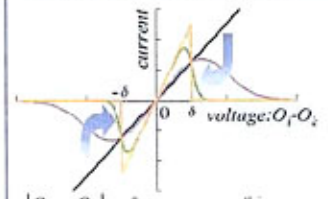
Target regions are correctly extracted by using resistive-fuse and nonlinear oscillator network models!

3. Resistive-fuse networks for image segmentation

resistive-fuse network



characteristic of a resistive-fuse



for effective smoothing processes

changing the resistive-fuse characteristic gradually

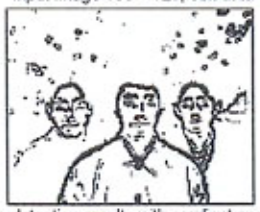
Resistive-fuse networks settle into a steady state when their power consumption E is minimum.

$$E = \sum_i \sum_{k \in N_i} \int_0^{O_j - O_i} G(V)\,dV + \sigma \sum_i (O_i - I_i)^2$$

resistive-fuse | linear resistance

We obtain the minimum value of E using the steepest descent method by PWM VLSI implementation.

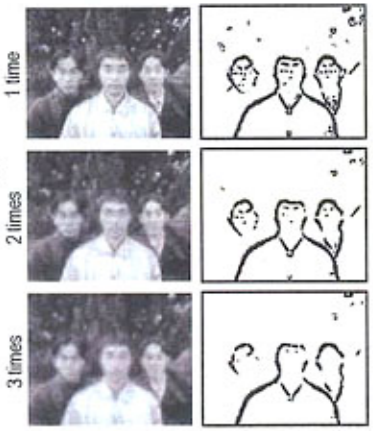
input image 150×120, 8bit data



edge detection results with gradient operator (sobel)
*Black expresses edges.

edge detection after smoothing

number of smoothing processes

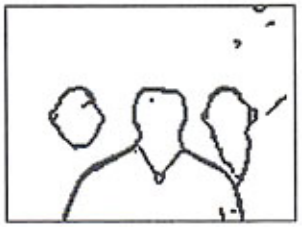


smoothing results | edge detection results

Imperfect segmented target regions exist!

image segmentation by resistive-fuse networks

segmented image

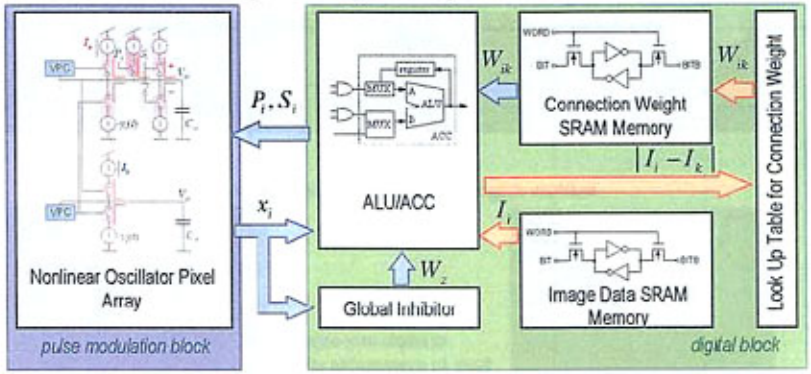


edge information image

Flexible image segmentation can be achieved by using the resistive-fuse network that extracts coarse region edges!

5. Merged/mixed-signal nonlinear oscillator network LSI

Schematic block diagram of a merged/mixed-signal nonlinear oscillator network circuit



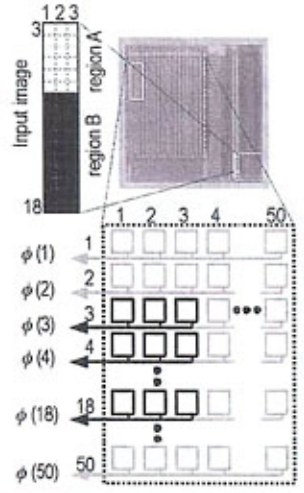
Operation flow in W_{ik} write mode

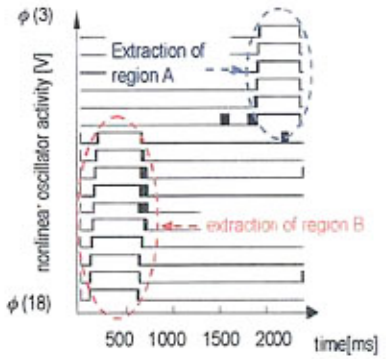
Operation flow in dynamics mode

micro-photograph of the chip

Specifications

Technology	0.35 μm CMOS 2-Poly 3-Metal
Die size	9 x 9 mm²
Supply voltage	3.3 V
Clock frequency	PWM 1 MHz Digital 100 MHz
Power consumption	PWM 20 mW Digital 200 mW
Number of pixels	50 x 50
Number of transistors	PWM 610 K Digital 870 K





measurement results with a 12.5MHz clock frequency

We can achieve sub-millisecond region extraction processing with the maximum operation frequency (100 MHz)!