Chapter 24
Image Edge Detection and Orientation Selection with Coupled Nonlinear Excitable Elements

Atsushi Nomura, Yoshiki Mizukami, Koichi Okada, and Makoto Ichikawa

Abstract. This chapter presents an image-processing algorithm for edge detection and orientation selection with discretely coupled nonlinear elements. The algorithm utilizes the nonlinear characteristic of the FitzHugh-Nagumo model and arranges the elements on an image grid system. The model is described with a pair of ordinary differential equations with activator and inhibitor variables, and exhibits mono-stable excitability. It was previously found that a grid system consisting of mono-stable nonlinear elements self-organizes pulses at crossing points between an initial activator distribution and a threshold level. In particular, the imposition of strong inhibitory coupling on the grid system causes stationary pulses at the crossing points. The algorithm presented here focuses on the phenomenon in which the grid system self-organizes stationary pulses at the crossing points. In addition, the algorithm introduces anisotropic coupling strength into the grid system; the coupling strength is decided according to the difference between the gradient direction of the inhibitor distribution and the specific orientation. An experimental section demonstrates the results of edge detection and orientation selection for artificial and real images.

24.1 Introduction

Nonlinear elements are common in nature and exhibit interesting temporal behavior such as nonlinear excitation and oscillation [1]. Very classical researches done

Atsushi Nomura
Faculty of Education, Yamaguchi University, Japan
e-mail: anomura@yamaguchi-u.ac.jp

Yoshiki Mizukami
Graduate School of Science and Technology, Yamaguchi University, Japan

Koichi Okada
Center for the Promotion of Higher Education, Yamaguchi University, Japan

Makoto Ichikawa
Faculty of Letters, Chiba University, Japan

K. Kyamakya et al. (Eds.): *Selected Topics in Nonlinear Dynamics*, SCI 483, pp. 429–448.
DOI: 10.1007/978-3-642-37781-5_24

in physiology showed that a nerve axon responds to an external stimulus and its state traces a nonlinear process of excitation and inhibition [2]. A chemical reaction system can also show nonlinear excitation or oscillation processes [3].

A system consisting of coupled nonlinear elements exhibits further interesting phenomena, such as self-organized pattern-formation processes. A reaction-diffusion system refers to a system of diffusely or continuously coupled nonlinear elements [1]. Some reaction-diffusion systems self-organize spiral waves and target waves traveling in space while others self-organize stationary periodic waves from initial uniform distribution.

Several researchers have found that a reaction-diffusion system has functions of information processing in addition to the function of information transmission. In a chemical reaction-diffusion system, an external stimulus initiates a target wave. The wave travels in space and reaches another point in space. If we artificially stimulate a point in the space of the reaction-diffusion system, and if we observe another point, we can find the traveling wave passing the observation point after a finite duration of time. This means that an information transmission system with traveling waves is established between the two points [4]. Another chemical reaction-diffusion system self-organizes waves in an area or along edges of an image-brightness distribution projected onto the system [5]. Thus, we can understand that a reaction-diffusion system also has the image-processing functions of edge detection and segmentation.

Image-processing functions can also be provided with a grid system of discretely coupled nonlinear excitable or oscillatory elements. A typical nonlinear element has activator and inhibitor variables; the activator variable excites the state of the element and the inhibitor variable inhibits the element from exciting. A grid system named LEGION (Locally Excitatory Globally Inhibitory coupled Oscillatory Network) performs image segmentation [6, 7]. We previously found that a grid system of nonlinear excitable elements with strong inhibitory coupling could also perform edge detection and segmentation [8–10].

This chapter presents an algorithm for edge detection and orientation selection with a two-dimensional grid system of discretely coupled nonlinear excitable elements. According to our previous findings [8–10], the algorithm utilizes a grid system consisting of nonlinear excitable elements. When a particular element has isotropic, strong inhibitory coupling to its neighboring elements, the system performs edge detection. When a particular element has anisotropic inhibitory coupling to its neighboring elements, the system performs orientation selection. A reaction-diffusion model with anisotropic inhibitory coupling originally demonstrated oriented periodic pattern formation in a biological system [11]. The algorithm presented here is obtained by replacing the anisotropic diffusion of the reaction-diffusion model with anisotropic discrete coupling. An experimental section shows that the algorithm indeed works for edge detection and orientation selection for artificial binary images and real gray-level images. In addition, the section demonstrates quantitative performance of the algorithm for noisy artificial binary images, in comparison with two representative existing algorithms proposed by Marr and Hildreth [12] and by Canny [13].