Edge Detection and Enhancement using Shunting Inhibitory Cellular Neural Networks

by

Carmine Pontecorvo, B.E. (Hons. I)

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Department of Electrical and Electronic Engineering

Faculty of Engineering

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Abstract

This thesis describes the application of shunting inhibitory cellular neural networks to the problems of edge detection and enhancement. Edge detection is needed in many mammalian and computer vision systems to reduce the vast amounts of incoming data to a relatively small number of features. Shunting inhibition describes the nonlinear interactions between sensory cells, and has been used to explain many nonlinear visual phenomena as found in the mammalian visual system. A cellular neural network (CNN) is a grid of locally connected, nonlinear parallel processing elements, able to process information in both space and time. CNN with shunting inhibition as the nonlinear interaction are referred to as SICNN.

This thesis begins with a general investigation of recurrent and feedforward SICNN systems. By linearising the feedforward SICNN using perturbation analysis, the frequency and impulse response characteristics are derived and its response to random (noisy) inputs is investigated. We also discuss how the SICNN can be designed to perform edge detection, and how the factors of the output and the SICNN parameters affect the performance.

Following this, we investigate how the SICNN parameters can be chosen to maximise edge detection performance given some optimality criteria. The SICNN weight distribution affects the edge detection performance, in particular the edge standard deviation and the hit rate. Hence an optimal weight distribution is derived using constrained optimisation to simultaneously optimise a number of criteria, namely the statistical measures of hit rate and edge standard deviation.

We also derive the SICNN decay factor which gives zero edge bias in the 1-D edge detection performance, which also optimises the hit rate and edge standard deviation. For input edges with multiplicative noise, this optimal decay factor is zero, but for additive noise, it is proportional to the noise standard deviation and the sum of weights. The constant of proportionality is empirically derived and tabulated for various weight distributions for both 1-D and 2-D synthetic edges. The SICNN performance with a number of different nonlinear activation functions is also investigated.

Next we investigate a number of postprocessing methods for the SICNN output. Most of
the methods involve the combination of the outputs of different SICNNs to improve the edge detection performance. The edges in the SICNN output are tracked as the neighbourhood size and the width of the weight distribution are slowly reduced, resulting in an improvement in the 1-D and 2-D edge detection performance.

The outputs of SICNNs with different weights and thresholding schemes are combined to give significant improvement in the performance, particularly for 1-D edges. The outputs of SICNNs with reversed weight distributions are also combined to improve the performance, especially for edges with small contrast. Finally, by examining the number of edges in the local neighbourhood of each edge pixel, spurious edges which may arise from noise can be eliminated, resulting in improved performance.

Having designed and optimised the SICNN for edge detection, we compare it to a number of standard edge detectors on both synthetic 1-D and 2-D images, as well as real 2-D images. The results indicate that the SICNN has better performance than the linear operators, particularly for inputs with multiplicative noise and on real images with both multiplicative and additive noise.

Finally, we look at the edge enhancement capabilities and properties of the SICNN. We investigate a number of different enhancement measures, and propose a new measure for step edges, called the Edge Enhancement Product (EEP). The EEP measures not only the edge enhancement, but also the difference in the background intensity levels of the step edge. When solving for the SICNN steady-state, the solution can be found using an iterative approach using a recursive sequence. The SICNN decay factor that maximises the EEP after 1 iteration of the sequence is derived and was shown to be the largest for different numbers of iterations. Thus, the output after 1 iteration is always used for image enhancement. The EEP is also used to find optimal parameters for other edge enhancers when the value of their parameters is not clearly defined. Finally, we compare the enhancement of both synthetic and real images using the SICNN and a number of standard edge enhancement techniques, and show that the SICNN is in general superior to the others, particularly for inputs with multiplicative noise.
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