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Neuro-fuzzy synergism to the intelligent system for edge detection and enhancement

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Abstract

The paper presents a fuzzy neural network system for edge detection and enhancement. The system can both: (a) obtain edges and (b) enhance edges by recovering missing edges and eliminate false edges caused by noise. The research is comprised of three stages, namely, adaptive fuzzification which is employed to fuzzify the input patterns, edge detection by a three-layer feedforward fuzzy neural network, and edge enhancement by a modified Hopfield neural network. The typical sample patterns are first fuzzified. Then they are used to train the proposed fuzzy neural network. After that, the trained network is able to determine the edge elements with eight orientations. Pixels having high edge membership are traced for further processing. Based on constraint satisfaction and the competitive mechanism, interconnections among neurons are determined in the Hopfield neural network. A criterion is provided to find the final stable result that contains the enhanced edge measurement. The proposed neural networks are simulated on a SUN Sparc station. One hundred and twenty-three training samples are well chosen to cover all the edge and non-edge cases and the performance of the system will not be improved by adding more training samples. Test images are degraded by random noise up to 30% of the original images. Compared with standard edge detection operators and enhancement techniques, the proposed system based on the neuro-fuzzy synergism obtains very good results.

Keywords: Fuzzy neural network; Edge detection; Edge enhancement; Hopfield neural network; Image processing

1. Introduction

Experiments with the human visual system show that edges in images are extremely important. Edges are also important features widely used in image processing, pattern recognition, and computer vision. A local edge is a small area in images where the local gray levels change rapidly in a simple way [1]. Most previous edge detection techniques used first-order derivative operators such as the Roberts edge operator [2], the Prewitt edge operator [3] and the Sobel edge operator [4]. If a pixel falls on the boundary of an object in an image, then its neighborhood will be a zone of gray-level transition. The Laplacian operator [5] is a second-order derivative operator for functions of two-dimension operators and is used to detect edges at the locations of the zero crossing. However, it will produce an abrupt zero-crossing at an edge and such zero-crossings do not always correspond to edges. Another gradient operator is the Canny operator [6] that is used to determine a class of optimal filters for different types of edges, e.g., step edges or ridge edges. A major point in Canny's work is that a trade-off between detection and localization emerged: as the scale parameter increases, the detection increases and localization decreases. In order to set the appropriate value for the scale parameter, the noise energy must be known. However, it is not an easy task to locally measure the noise energy because both noise and signal affect any local measure.

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The Kirsch masks [1], Robinson masks [7], Compass Gradient masks [8], and other masks [9] are popular edge-template matching operators. Although the edge orientation and magnitude can be estimated rapidly by determining the largest response for a set of masks, template mask methods give rise to large angular errors and do not give correct values for the gradient.

Many edge detectors rely totally on gray-level differences for their approximation of the image gradient function either directly or by representing these differences in a more analytical form such as the Huekel edge detector [10]. Other approaches include attempts at identifying the type of edge as well as the edge position to subpixel accuracy by analyzing the location and type of phase congruence of Hilbert–Fourier representations using local energy characteristics [11]. However, the latter method has not been demonstrated to work in noisy images.

There has been an explosive growth in the study of relaxation labeling techniques for image processing, such as image restoration [4], edge enhancement [12], edge detection [13–16], and image segmentation. Relaxation labeling uses contextual information to resolve object labeling ambiguities as locally as possible. The amount of contextual information employed is expanded recursively until a unique labeling result. The problem of relaxation labeling was first described by Rosenfeld et al. [16].

The statistical or stochastic methods for boundary extraction, such as Markov random field [17,18] and MAP estimation [19] do not perform very well since these methods lack a powerful two-dimensional structure knowledge. The statistical measurement for edge detection is much less powerful than fuzzy systems since the statistical process employs only a single formula for all the different edge patterns.

As a matter of fact, we cannot recognize an edge with 100% confidence. Uncertainty arises because of ambiguity or lack of information or evidence. In recent years, an increasing number of researchers have been involved in the subject of fuzzy neural networks (FNNs) [20–26] in the hope of combining the strengths of fuzzy logic and neural networks and achieving a more useful tool for fuzzy information processing and for exploring the functioning of human brains. Neural networks are considered a sort of model-free signal processing device [27,30]. They map data points in input data space to points in output data space. The training data points should be properly distributed and sufficiently dense [28]. On the other hand, fuzzy neural networks try to reduce the requirements on the training data sets by incorporating expert knowledge within the fuzzy concept. They perform a set-to-set mapping. This is achieved by adding point-to-set (fuzzify) and set-to-point (defuzzify) conversion to the input and output, respectively.

A fuzzy filter and edge detection technique was introduced by Tyan and Wang [29]. The fuzzy rules are used for contrast enhancement, requiring arbitrary definitions of dark and bright pixels, which the authors admit require adjustment by a human operator. Images are further enhanced by an interesting fuzzy low-pass filter. The edge detection scheme also relies on arbitrary dark and bright definitions (again requiring user adjustment), and operates on a 2×2 area. A fuzzy edge detection technique was also introduced by Tao and Thompson [21]. In this technique, 16 possible edge structures in a 3×3 area are considered, and fuzzy edge membership is determined by fuzzy if–then rules. After redundant edge pixels are discarded, the remaining edge pixels are thresholded based on a noise factor. Neither of the techniques above acknowledge the possibility of various edge shapes such as corners and triple points, leaving gray-level differences among immediate neighbors as the only determining factor in edge extraction. Furthermore, both techniques operate on very small regions, ignoring the possibility of broader edges in the process.

In the first phase of our research, before using the proposed fuzzy neural network for edge detection, an adaptive fuzzification procedure is used to normalize input patterns, and a window division method is also applied to each pattern. The proposed FNN is a three-layer feedforward neural network that takes the input pattern in a noise corrupted image and produces the edge credit as intermediate results for non-edge or edge measures with one of eight orientations. Hence, there is one non-edge credit map and there are eight edge credit maps. For many complex real-world images, all the above edge detection systems (including FNN which is much better than other mask operators) will yield unsatisfactory results due to noise, gradual variations in gray-level or non-uniform lighting. In other words, these results contain false, missing, and weak edges. In the second phase of our research, stable structures for edges are analyzed by discovering an energy function whose minimum should correspond to the possible stable situations. Based on the constraint satisfaction, the competitive mechanism, and the energy function, the structure of a Hopfield neural network is designed. It efficiently captures the topological and structural properties of the edge data obtained from the first phase. This leads to updating the neural computation toward the right solution by establishing proper interconnections among neurons.

This paper analyzes the problem of edge detection and provides a summary of the research on the topic. Adaptive fuzzification is introduced in Section 2 to obtain the membership function for measuring the relative darkness and brightness. In Section 3, an input pattern in the window form is arranged such that the structure information can be fully utilized. The structure of FNN and the training of FNN are provided in Section 4. Edge maps are obtained for further edge enhancement. Hopfield neural networks are discussed in Section 5. The system accomplished the tasks of reinforcing true edges, recovering missing edges, and suppressing false edges. In Section 6, experiments are reported in comparison with other major edge detection techniques. The paper finishes with concluding remarks in Section 7.