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Cellular neural networks and computational intelligence in medical image processing

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Abstract

The principal constituents of computational intelligence are fuzzy logic, neural networks and evolutionary algorithms, with emphasis in their mutual enhancement. The present paper reviews some applications of these formalisms in the area of medical image processing, where advantage is taken from the ability of fuzzy logic to work with imprecise information, the ability of neural networks to learn a system's behavior from representative examples and the ability of evolutionary algorithms to optimize complex systems, particularly when no mathematical model is available. The paper focuses mainly on neural networks in medical image processing. A special kind of cellular neural networks based on multiple valued threshold logic in the complex plane will be presented and its efficacy for medical imaging will be documented. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Computational intelligence; Cellular neural networks; Medical image processing

1. Overview of computational intelligence in medical image processing

Neural networks are well known for their good performance in classification and function approximation. They have been used with success in medical image analysis, particularly in the case of signal classification in support of diagnosis, but also for signal filtering, compression and restoration (see, e.g. Miller et al. [1], Hilera et al. [2]). In the present paper, applications and possibilities of neural networks, particularly of a class of cellular neural networks in medical image processing are considered. The main operations in this case are filtering, segmentation and edge detection. A preliminary report on the following aspects was presented at the 5th International Conference on Fuzzy Logic, Neural Nets and Soft Computing, Iizuka, 1998 (see, Hiltner et al. [3]).

Adaptive filtering with neural networks to cancel maternal heartbeat when recording the ECG of an unborn child is one of the earliest known medical signal processing application of neural networks (see, Widrow and Winter [4]).

Segmentation is a basic operation in medical image processing and it involves the recognition and localization of a subpattern within an image. A very closely related problem associated with pre-processing for segmentation is the position, scale and rotation invariant recognition of regions of interest. Neural networks have been successfully used to solve different aspects of this problem (see, e.g. Grönqvist and Lenz [5], Katz and Merickel [6], Spirkovska and Reid [7], You and Ford [8]). Interactive segmentation has been reported in Haring and Kok [9], where neural networks have been used to optimize filter parameters (see, Haring et al. [10]). Properly trained neural networks exhibit a good generalization ability. This supports their application in forecasting problems. Forecasting the position of a region of interest with a neural network previous to segmentation has been explored by Rittscher et al. [11]. A feedforward neural network is trained with a set of points defining a polygonal approximation of the (main vertical projection of the) skull of test subjects as input and a set of points defining a polygonal approximation to the region of interest in the brain of the same individuals as output. After proper training, the neural network is used to forecast the (possibly imprecise) position of the corresponding region of interest in a new subject, given the polygonal approximation of its skull (see Fig. 1). Fig. 2 illustrates the result of forecasting the polygonal approximation to the brain of a test subject.

Another important operation in medical image processing is edge detection. Standard feedforward neural networks

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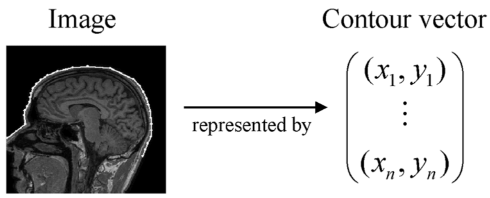

Fig. 1. Head contour approximated by a polygon and represented as a vector with n points.

have been applied to solve this problem (see, Srinivasan et al. [12]). Aizenberg et al. [13] have introduced a new kind of cellular neural network with multiple-valued neurons working in the complex plane. These networks have been very successfully and efficiently applied to edge detection and filtering in medical images (see, Aizenberg [14,15], Aizenberg et al. [16]). This kind of cellular neural network will be discussed in detail in the next section. Finally, quite a promising emerging idea is the combination of neural networks and intelligent agents in medical image processing, as suggested by Poli and Valli [17].

Fuzzy logic is well known for its capability of representing and processing imprecise information. The idea of coping with uncertainty in image processing was already discussed in Gupta and Knopf [18]; however, probably the best known applications of fuzzy logic related to picture processing in a broad sense are fuzzy clustering and fuzzy pattern recognition (see, e.g. Bezdek [19], Gath and Geva [20], Bezdek and Pal [21], Krishnapuram and Keller [22]). Combination of fuzzy logic with neural networks have also been applied for this task (see, e.g. Bezdek et al. [23], Simpson [24,25], Kwan and Cai [26]) and for more specific picture processing tasks, like edge detection (see, e.g. Kim et al. [27]). Furthermore, image enhancement by means of fuzzy logic has also been investigated (see, e.g. Pal and King [28], Tizhoosh et al. [29], Tizhoosh [30]). Segmentation of medical images with fuzzy matching techniques has been discussed in Kobashi et al. [31], by using fuzzy filtering, in Hiltner [32] and Hiltner et al. [3,33,34], and by means of fuzzy clustering, in Runkler and Bezdek [35]. Applications of the Hough transform for the detection of lines in pictures are well established (see, e.g. Duda and Hart [36]). The fuzzy Hough transform allows, however, detecting rough linear picture elements as well as elements with linguistically defined curvature (see Han et al. [37], Chatzis and Pitas [38]). These and other applications of fuzzy logic in medical image processing will be treated in depth in other papers of this issue and therefore they will not be further detailed here.

Evolutionary algorithms have been applied to optimize both neural networks (see, e.g. Han et al. [39]) and fuzzy systems (see, e.g. Cordón and Herrera [40]), thus indirectly contributing to medical applications. There are, however, more direct contributions. Genetic algorithms have successfully been applied for finding diagnostic rules from a urological database, as reported in Laurikkala and Juhola [41]; to the selection of medical cases in Kuncheva [42] and to the qualitative improvement of clinical diagnostic abilities in Lopes et al. [43]. Evolutionary algorithms for medical image processing have been reported in Brink et al. [44,45] and Bonsaythip and Alander [46]. Combining evolutionary systems with autonomous agents, as suggested in Liu et al. [47], seems to be a promising alternative for image processing.

2. Basics of cellular neural networks

Cellular neural networks (CNNs) were introduced in Chua and Yang [48,49] and have become a very appropriate computing model for the solution of different kinds of image processing problem. CNNs based on multi-valued neurons introduced in Aizenberg and Aizenberg [50], and CNNs based on universal binary neurons disclosed in Aizenberg and Aizenberg [51] are particularly efficient for image processing and will be discussed in detail below. Both multi-valued neurons (MVN) and universal binary neurons (UBN) work with complex-valued weights and complex internal arithmetic. An MVN can realize arbitrary multiple-valued functions and a UBN, any (not only threshold) Boolean function. Together with noise removal, by using CNNs based on these complex-valued neurons it is possible to implement filters, which can amplify high and medium frequencies [14]. These filters are very good for solving the

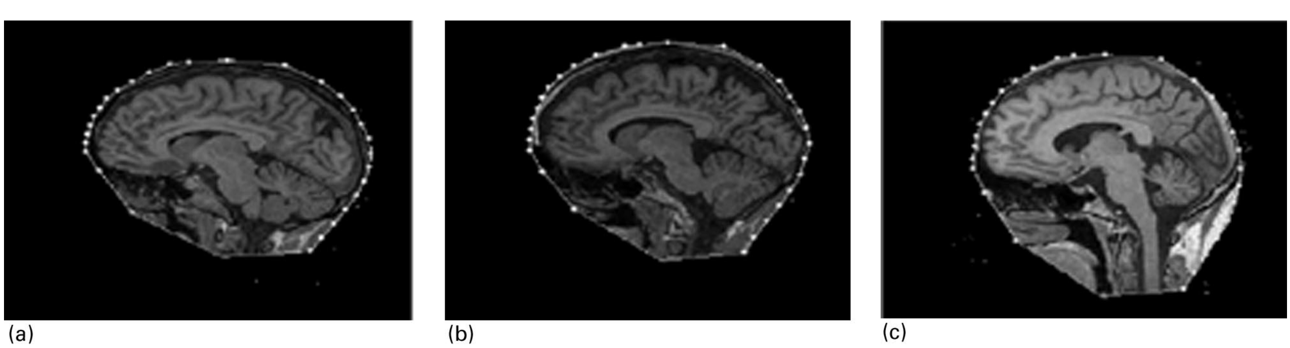

Fig. 2. Some ROI-results with different quality levels.