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Image processing for medical diagnosis using CNN

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Abstract

Medical diagnosis is one of the most important area in which image processing procedures are usefully applied. Image processing is an important phase in order to improve the accuracy both for diagnosis procedure and for surgical operation. One of these fields is tumor/cancer detection by using Microarray analysis. The research studies in the Cancer Genetics Branch are mainly involved in a range of experiments including the identification of inherited mutations predisposing family members to malignant melanoma, prostate and breast cancer. In bio-medical field the real-time processing is very important, but often image processing is a quite time-consuming phase. Therefore techniques able to speed up the elaboration play an important rule. From this point of view, in this work a novel approach to image processing has been developed. The new idea is to use the Cellular Neural Networks to investigate on diagnostic images, like: Magnetic Resonance Imaging, Computed Tomography, and fluorescent cDNA microarray images.

Keywords: Image processing; Medical diagnosis; Cellular neural network; DNA microarray

1. Introduction

The old definition of image processing was manipulation of image by computer subjecting a numerical representation of an object to a series of operations in order to obtain a desired result. Instead, in this work a new definition of image processing has been considered, the manipulation of images occurs by CNN, that is an array of simple, identical, locally interconnected nonlinear dynamic circuits, named cells, used to build large scale analog signal processing systems. CNN cells can be arranged in one, two or three-dimensional arrays organized in a linear, rectangular or parallelepiped grid. A simple correspondence between the pixel of the image and the input of the each cell allows to perform all the image processing operations.

The main advantage of using CNNs in image processing is related to the increasing of throughput due to the massive parallelism of the structure, joined to the analog way of signal processing, typical of CNNs. In fact they are able to perform a complete image processing analysis in time of order of 10^{-6} s (by using a CNN hardware implementation), this in form of sequences of simple tasks like: array target segmentation; background intensity extraction; target detection and target intensity extraction, in time of the order of 10^{-4} s when a hardware implementation of CNN was considered.

It is important to notice that only a two-dimensional CNN, composed by 64×64 cells, is available at the moment in a physical circuit [1].

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The three-dimensional structures introduced in this paper are obtained by simulation [2].

Some examples of applications in radio-surgery and microarray image analysis are reported. In the radio-surgery applications two different cases are analyzed, in the first case the target is to discover the median line of a tumor region from a 3D model made from a set of diagnostic images of brain. The speed of this image elaboration is essential to help the surgeon in the tumor removal by using gamma knife based radio-surgery (^{60}Co). In the second case an innovative three-dimensional reconstruction of the third cerebral ventricle of brain is illustrated.

Moreover in the last application the microarray image analysis has been performed in order to extract sample intensities or ratios, at each printed cDNA location in a given microarray scan. The advantage of the high performance is the identification of genes involved in the development of malignant characteristics in cancer cells easily and quickly.

The paper is organized as follows. In Section 2 an overview of the CNN is presented, in Section 3 the applications that have been studied are described, and finally in Section 4 all the major findings are summarized and the future development of this technique are outlined.

2. Cellular neural network

Cellular Neural Networks (CNNs) were introduced by Chua [3,4] in 1988; they are neural architectures particularly suited for image processing applications. The new three-dimensional CNN array is considered, where the cell dynamics are described by the following set of differential equation:

$$\begin{aligned}\dot{x}_{ijk} = & -x_{ijk} + \sum_{lmn\in N_r} A_{ijk,lmn}y_{lmn}(t) \\ & + \sum_{lmn\in N_r} B_{ijk,lmn}u_{lmn}(t) \\ & + \sum_{lmn\in N_r} C_{ijk,lmn}x_{lmn}(t) + I \end{aligned} \tag{1}$$

$$y_{ijk}(t) = f\left(x_{ijk}(t)\right) = \tfrac{1}{2}\left(\left|x_{ijk}(t)+1\right| - \left|x_{ijk}(t)-1\right|\right) \tag{2}$$

where the subscript *ijk* refers to a grid point associated with a cell on the 3D space. It is a generalized version, for a three-dimensional grid, of the State Controlled CNN [5]. The variable $x_{ijk}(t)$ is the state, $y_{ijk}(t)$ is the output, $u_{ijk}(t)$ is the input of the cell; $A_{ijk,lmn}$, $B_{ijk,lmn}$, $C_{ijk,lmn}$ are the feedback template, the control template, the state template, respectively; I is the bias and f is the piece-wise linear output function described by (2); $ijk \in N_r$ is a grid point in the neighborhood within the radius r of the cell *ijk:*

$$\begin{aligned} N_r(i,j,k) = \{ & C(l,m,n) : |i-l| \le r, \\ & |j-m| \le r, |k-n| \le r\}. \end{aligned} \tag{3}$$

By choosing the feedback template, the control template, the state template, the bias value, I, the input and the initial state value of the cells of the CNN a huge number of operations can be performed; they work like the *operations* in a program.

On the other hand, in the usual image processing, the input and the initial state of each cell constitute the *operator*, and are the normalized values of the pixels of the image. Often several interesting fields require three-dimensional image processing. This new task can be fulfilled by considering the 3D CNN introduced in Eq. (1) and introducing the spatial image layer by layer.

To realize the three-dimensional analysis (described in the next Section) a new three-dimensional CNN simulator [2] has been developed, meanwhile for the Microarray analysis the CNNUC3 prototype [1] has been used. This prototype consists in an array of 64×64 elementary cells, that computes a logic operation on an image of 64×64 pixels in 100 ns, meanwhile a Pentium II 400 Mhz spend 30 μs for the same operation.

3. Applications

The possibility of simulating 3D CNN structures suggests huge fields of applications, some of these are presented in the following subsection.

Some interesting applications of 3D image processing have been found in biomedical field: here briefly two examples of such applications in radiosurgery [6] and neurosurgery are reported. The first consists of finding the median line of a tumor region, the second illustrates an innovative three-dimensional reconstruction of the third cerebral ventricle of brain.

The third example is relative at the microarray analysis, in which an innovative selection of bright spot is reported.

3.1. Median line of a tumor region

The median line of a tumor is the zone where a gamma ray radiotherapy can be applied; in fact the surgeon may choose the optimum dose for the gamma ray shoot on tumor, controlling that the number of healthy shot cells is minimized. For this purpose, a three-dimensional model of the human head is built from computed tomography (CT) or magnetic resonance images (MRI). An algorithm for this task was developed: a fixed state mask selects the region of the tumor, a threshold triggered template on the tumor gray level is applied and finally a noise removal template is used. Now the tumor region is insulated by the remaining part of head. These operations are performed in parallel on each layer of the three-dimensional image, so as to speed up the whole process.

Fig. 1 shows the tumor region insulated by the first part of the algorithm and a superposition of the median line on this region.

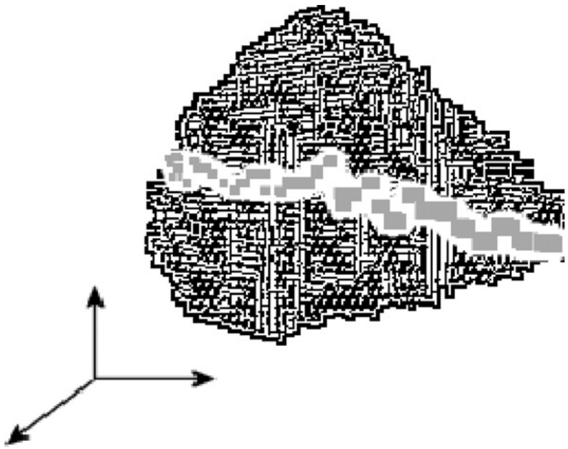

Fig. 1. Insulated tumor region and its median line found with the algorithm described.

3.2. Reconstruction of third cerebral ventricle

The reconstruction of the third cerebral ventricle is fundamental when the surgeon wants to retrieve the coordinates of the anterior and posterior commissura useful in certain surgical operations for the Parkinson disease, and the only diagnostic available exam is the magnetic resonance. This examination does not show on the same image the two commissura. So a preprocessing alignment of these two points on the same image is needed. Using a CNN to do this task a time saving is possible, and considering the criticality of a surgical operation, all the time saved is very important.

The developed algorithm selects the ventricle and detect the commissuras position with a fixed state mask, a threshold triggered and a figure reconstruction, after a rotation is actuate to have the two commissuras on the same plane. In Fig. 2 a comparison between the model retrieved and an image from the literature has been shown.

3.3. Microarray analysis

The recent rapid progress in large-scale genomic sequencing has been obtained by the improvements both in the area of biological protocols and in the availability of improved laboratory instrumentation [7]. In the last years alternative technologies have become faster and able to target specific genomic sequences [8]. One of these techniques is the DNA-chip, which uses array hybridization and standard photolithographic methods. The greatest advantage of this process is that the time required to synthesize the oligonucleotides is independent from their length, because the sequences are synthesized in parallel. The data readout for DNA-chip are principally fluorescent images, where the spot intensity is proportional to hybridization. Classical image processing operation on this spot is time consuming, thus an algorithm able to classify the spots by using the Cellular Neural Networks Universal Machine (CNNUM) paradigm has been advantageous.

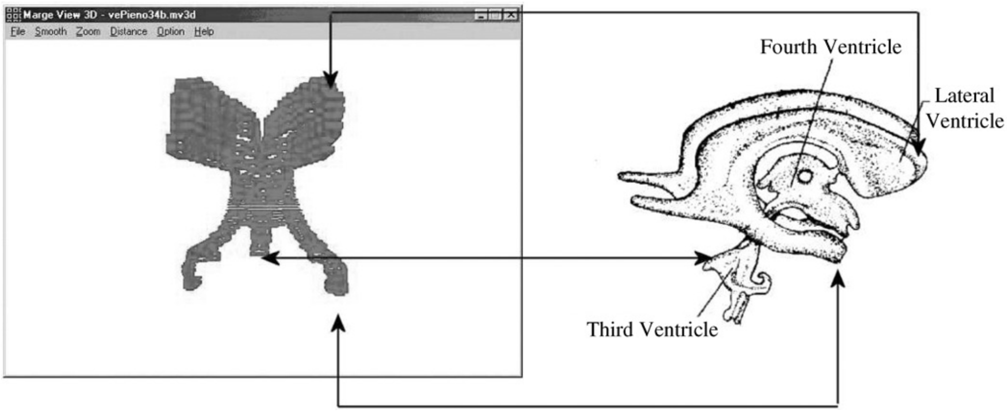

Fig. 2. Reconstruction of third-ventricle from experimental data; on left-hand side the output of the 3D visualizator and on right an image from literature; in both the common parts are highlighted. Note that the fourth ventricle (in center of right image) is not considered in the reconstruction.

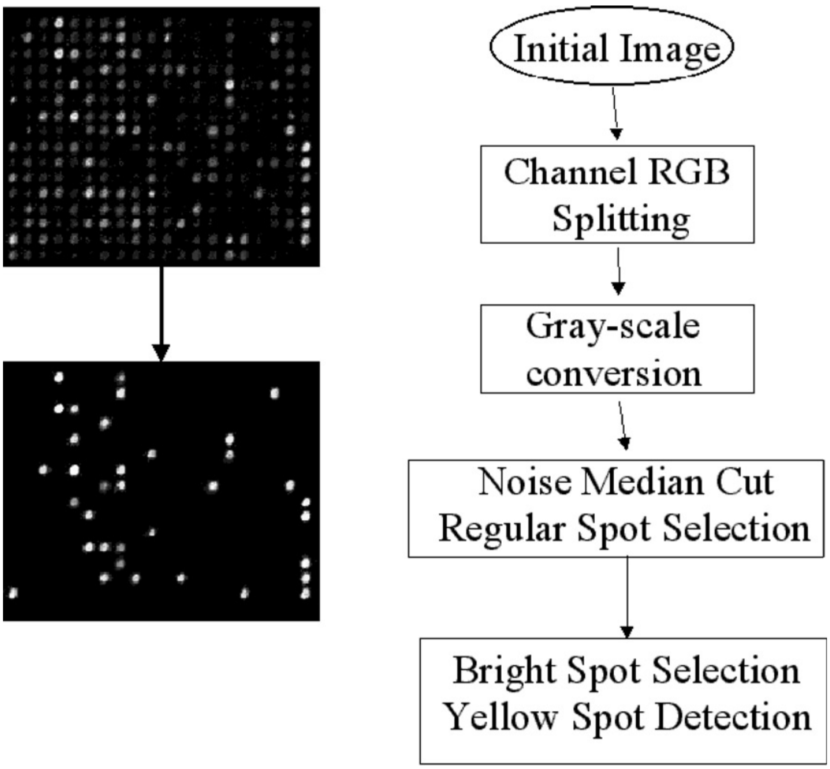

Fig. 3. The initial fluorescent image and the algorithm that extract the brighter spot.

An important peculiar property of a CNNUM is a one-to-one geometric correspondence between the sensing inputs and the processor. Every cell has its own sensory input integrated on the chip that allows to use a fully parallel input.

In this way, a parallel image analysis is associated to a parallel biomedical protocol. The main advantages of this application are the speed of computation, joined to an appreciable accuracy. In Fig. 3 the initial and final fluorescent images are shown, and the algorithm that extract sample intensities or ratios is also presented.

4. Conclusions

Our work has shown that a three-dimensional CNN can perform many image processing operations, increasing the speed of the procedure in comparison with classical techniques. These operations are very important in medical fields, where the time is an important parameter that can help the surgeon both for diagnosis and before and during the surgical operation. The future task of this work is to increase the precision (near 0.1 mm), so that an integral neurosurgery application will become possible.

Regarding the microarray images, the optimal results obtained by CNN chip suggest a larger use of it to validate this research field.

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