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Image Processing of Gray Scale Images by Fuzzy Cellular Neural Network

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Abstract

In this study, we investigate the Fuzzy CNN proposed by T. Yang and L.B. Yang, and apply the Fuzzy CNN to three image processings of gray scale images. One can see that the integration of fuzzy operations into the CNN results in nonlinear synaptic laws. These fuzzy synaptic laws have great potential in image processing because of above three examples. We confirm its effectiveness.

1. Introduction

Cellular neural network (CNN) have been previously considered for many applications related to image processing. And it is known that CNN is a very effective tool for image processing. However, in every phase of image processing, there exist many uncertainties.

Fuzzy set theory provides the mathematical strength to capture these uncertainties. In [1], fuzzy set theory is integrated into the CNN paradigm to give birth to a new image processing paradigm, the Fuzzy CNN, which will become a powerful tool for image processing problems. From the beginning of the CNN, all structures and algorithms have been closely concerned with its realization by state-of-the-art VLSI technology. The design of Fuzzy CNNs should keep this tradition, e.g. local connectedness between neurons (cells) and simple cell structures.

In [1], there are only a few application examples to the gray scale images, and detailed operation has not been clarified. In this study, we research the Fuzzy CNN in more detail, and apply it to gray scale images by various fuzzy operations. We present the effectiveness of the Fuzzy CNN.

2. Architectures of Fuzzy CNN [1]

The Fuzzy CNN has almost the same architecture as the original CNN. We denote the cell in the *i* th row and *j* th column as cell C_{ij}. The circuit of C_{ij} is shown in Fig. 1, where the suffixes *u*, *x* and *y* denote input, state and output, respectively.

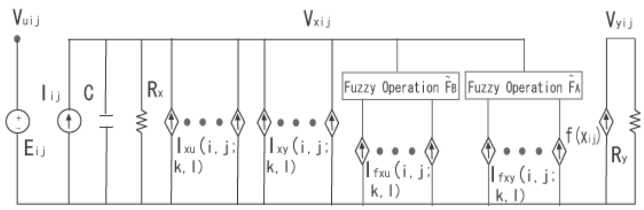


Fig. 1 Circuit of cell C_{ij} in Fuzzy CNN.

The state equation of the cell C_{ij} is defined by the following equation.

$$\begin{aligned} C\frac{dv_{xij}(t)}{dt} &= -\frac{1}{R_x}v_{xij}(t) \\ &+ \sum_{C_{kl}\in N_r(i.j)} A(i,j;k.l)v_{ykl}(t) \\ &+ \sum_{C_{kl}\in N_r(i.j)} B(i,j;k.l)v_{ukl}(t) + I \qquad (1) \\ &+ \widetilde{F}_{AC_{kl}\in N_r(i.j)}(A_f(i,j;k,l)v_{ykl}(t)) \\ &+ \widetilde{F}_{BC_{kl}\in N_r(i.j)}(B_f(i,j;k,l)v_{ukl}) \end{aligned}$$

Output and input equations are the same as the original CNN. $A_f(i,j;k,l)$ and $B_f(i,j;k,l)$ are the synaptic weights used by fuzzy operations $\widetilde{F}_{AC_{kl}\in N_r(i.j)}(\cdot)$ and $\widetilde{F}_{BC_{kl}\in N_r(i.j)}(\cdot)$; A_f and B_f should be chosen in accordance with the application. $\widetilde{F}_A(\cdot)$ and $\widetilde{F}_B(\cdot)$ denote two fuzzy local operators defined in $N_r(i,j)$, which may be any fuzzy logical expressions combined by fuzzy OR '$\widetilde{\vee}$' and fuzzy AND '$\widetilde{\wedge}$'.

Therefore, equation (1) can be rewritten as follows.

$$\begin{aligned} C\frac{dv_{xij}(t)}{dt} &= -\frac{1}{R_x}v_{xij}(t) \\ &+ \sum_{C_{kl}\in N_r(i.j)} A(i,j;k.l)v_{ykl}(t) \\ &+ \sum_{C_{kl}\in N_r(i.j)} B(i,j;k.l)v_{ukl}(t) + I \end{aligned}$$

$$
\begin{aligned}
&+ \quad \widetilde{\bigwedge}_{C_{kl} \in N_r(i.j)} A_{fmin} v_{ykl}(t) \\
&+ \quad \widetilde{\bigvee}_{C_{kl} \in N_r(i.j)} A_{fmax} v_{ykl}(t) \qquad (2) \\
&+ \quad \widetilde{\bigwedge}_{C_{kl} \in N_r(i.j)} B_{fmin} v_{ukl}(t) \\
&+ \quad \widetilde{\bigvee}_{C_{kl} \in N_r(i.j)} B_{fmax} v_{ukl}(t)
\end{aligned}
$$

where A_{fmin}, A_{fmax}, B_{fmin}, B_{fmax} are the feedack MIN, feedback MAX, feedforward MIN, feedforward MAX templates, respectively.

In this study, we use two fuzzy logical expressions, fuzzy OR '$\widetilde{\vee}$' and fuzzy AND '$\widetilde{\wedge}$'. Fuzzy OR means that the largest value in fuzzy templates is chosen as fuzzy synaptic weights. In order to use 1-neighborhood template here, Fuzzy OR chooses the largest value in 9 values. Fuzzy AND means that the smallest value in fuzzy templates is chosen as fuzzy synaptic weights. In order to use 1-neighborhood template here, Fuzzy AND chooses the smallest value in 9 values.

3. Image processing examples

Now, we apply the fuzzy CNN to a gray scale image shown in Fig. 2.

Fig. 2 Original image.

3.1. Logic NOT operation

The first image processing is Logic NOT. The original template for binary image is

$$
A = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}, \; B = \begin{bmatrix} 0 & 0 & 0 \\ 0 & -2 & 0 \\ 0 & 0 & 0 \end{bmatrix}, \; I = 0.
$$

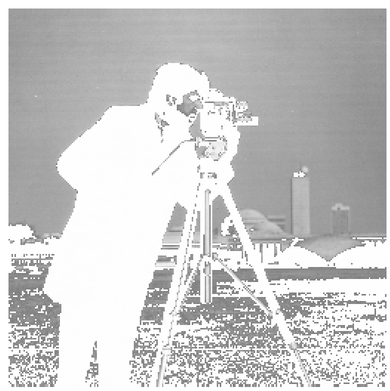
We apply the following fuzzy template with the fuzzy AND logic.

$$
A_{fmax} = B_{fmax} = 0 \ ,
$$

$$
A_{fmin} = B_{fmin} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}.
$$

The results are shown in Fig. 3. Because a part of gray scale is black and becomes binary image in (a), the NOT operation can not be performed well. However, in (b), a part of gray scale is not black and does not becomes binary image. So the Fuzzy CNN performs the Logic NOT operation of grey scale image.

(a) using original CNN.



(b) using Fuzzy CNN.

Fig. 3 Logic NOT operations.

3.2. Edge detection

The second image processing is Edge detection. The original template for binary image is

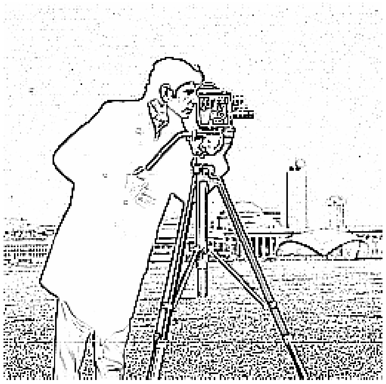
$$
A = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}, \; B = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}, \; I = -0.5.
$$

We apply the following fuzzy template with the fuzzy AND logic.

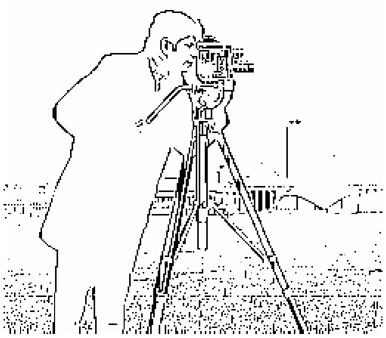
$$
A_{fmax} = B_{fmax} = 0 \ ,
$$

$$
A_{fmin} = B_{fmin} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \end{bmatrix}.
$$

The results are shown in Fig. 4. We can see that the Fuzzy CNN extract the edges in the gray scale image very well. However, in the original CNN, there exists many noises. Therefore, the original CNN cannot perform well.



(a) using original CNN.



(b) using Fuzzy CNN.
Fig. 4 Edge detection.

Next, we try to detect edges of a gray scale image shown in Fig. 5 by using two fuzzy logical expressions, fuzzy OR and fuzzy AND, simultaneously.

Fig. 5 Original image.

We apply the above templates, and the results are shown in Fig. 6. Though Fuzzy CNN can remove the noise well in comparison with the original CNN, there are a lot of places where the edges disappear.

(a) using original CNN.

(b) using Fuzzy CNN.
Fig. 6 Edge detection.

We try to add a fuzzy OR template in addition to a fuzzy AND templates. The fuzzy templates are shown in the folowing.

$$A_{fmax} = \begin{bmatrix} 0 & 0.1 & 0 \\ 0.1 & 0.3 & 0.1 \\ 0 & 0.1 & 0 \end{bmatrix}, \; B_{fmax} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0.1 & 0 \\ 0 & 0 & 0 \end{bmatrix},$$

$$A_{fmin} = B_{fmin} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \end{bmatrix}.$$

The result is shown in Fig. 7. By using both fuzzy OR templates and fuzzy AND templates, the Fuzzy CNN extract the edges and remove noise well.

Fig. 7 using Fuzzy AND and OR templates.

4. Conclusions

In this study, we have investigated the Fuzzy CNN proposed by T. Yang and L.B. Yang, and applied the Fuzzy CNN to three image processings of gray scale images. One can see that the integration of fuzzy operations into the CNN results in non-linear synaptic laws. These fuzzy synaptic laws have great potential in image processing because of above three examples. We have confirmed its effectiveness.

References

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