New emulated discrete model of CNN architecture for FPGA and DSP applications

Martínez J.J., Toledo F.J., Fernández J.M.

Dpto. Electrónica, Tecnología de Computadoras y Proyectos
Universidad Politécnica de Cartagena. Campus Muralla del Mar, C/ Dr. Fleming s/n
30202 Cartagena, Spain

Corresponding author: jjavier.martinez@upct.es

Abstract. A new approach to Cellular Neural Networks discrete model is proposed. This approach is focused on CNN implementation on reconfigurable hardware architectures and DSP microprocessors. CNNs are analysed from the perspective of Systems Theory, giving rise to an alternative model to those found in the literature available. Dynamic equations and their solutions, stability analysis and real-time implementation architecture are described in this paper as the most relevant points in the development of our model. The main results, obtained from different simulations, evidence the usefulness and functionality of the model.

1 Introduction

Cellular Neural Networks, introduced by Chua-Yang [1], are the basis of both Discrete-Time Cellular Neural Networks (DT-CNN) [2] and Cellular Neural Networks Universal Machine (CNN-UM) [3]. One of the most important features in CNN paradigm is local connectivity, i.e., any cell is connected only to cells in a neighbourhood of a determined radius. However, this constraint does not avoid global processing, which is possible thanks to propagation and relaxation of information all along the network. The cells in a CNN can be identical, like Linear Cloning Template CNN (LTC-CNN), or belong to any group within a small number of groups, for example biological neurons. The structure in arrays of invariant in space and locally connected cells have led to study and develop VLSI implementations based on the CNN-UM previously mentioned: computers with analog and digital (analogic) elements, programmable by a single fixed-length template.

Nevertheless, the asynchronous nature of CNNs and precision requirements in some applications considerably hinder the design on analog ASIC devices of these structures. On the other hand, nowadays, there exists a rising interest in digital signal processing and its implementation, not only on specific processors (DSP) but also on hardware reconfigurable devices (FPGA). This offers new possibilities for CNNs, considerably increasing the techniques and the resources available for their development and implementation.

A new discrete model for CNN is presented in this paper. The cell model formal description and the global mathematical behaviour of the system have been...
derived from Systems Theory. Dynamic equations have been formulated and resolved by finite difference, providing a tool for analysing and studying asymptotic stability of the model. The proposed architecture, obtained as the conclusion of our development, is oriented to the CNN implementation on hardware reconfigurable devices (FPGA) and on digital signal processors (DSP), offering a new alternative to those described in the related literature [4], [5], [6], [7]. Finally, different simulations and results are presented, illustrating the advantages of the proposed architecture and the methodology used in its synthesis.

The outline of this paper is as follows. In Section 2 the DT-CNN model is described and formulated, solving the corresponding equations. Next, model’s stability is studied and analysed in Section 3. The architecture of implementation and the results are presented in Section 4, and then, conclusions in Section 5 to finish with.

2 CNN Model in System Theory

The dynamics defining behaviour of Chua-Yang Cellular Neural Network is given by the state equation (1) and by the activation function \( f(x_{ij}) \) (2):

\[
C \frac{dx_{ij}}{dt} = -\frac{1}{R} x_{ij} + \sum_{k,l \in N_r(i,j)} A_{kl} y_{kl} + \sum_{k,l \in N_r(i,j)} B_{kl} u_{kl} + I_{ij},
\]

\[
y_{ij} = f(x_{ij}) = \frac{1}{2} (|x_{ij} + 1| - |x_{ij} - 1|),
\]

where \( I, u, y, x \) denote input bias, input, output and state variable of each cell, respectively. Neighbourhood distance \( r \) for cell \((i, j)\) is given by \( N_r(i,j) \) function, where \( i \) and \( j \) denote the position of the cell in the network and \( k \) and \( l \) the position of the neighbour cell relative to the cell in consideration. \( B \) is the constant weights template for inputs feedback and \( A \) is the corresponding template for the outputs of neighbour cells. Finally, non-linear activation function of output corresponds to piecewise linear operator (PWL).

\[
X_{ij} = \frac{\sum_{k,l \in N_r(i,j)} A_{kl} Y_{kl} + \sum_{k,l \in N_r(i,j)} B_{kl} U_{kl} + I_{ij}}{CS + \frac{1}{R}}.
\]

It is possible to rewrite the state equation (1) by Laplace Transform (3). However, this transfer function has the disadvantage of implicitly associating state variable \( X_{ij} \) to non-linear output variable \( Y_{ij} \). Nevertheless, this non-linearity problem in the transfer function can be overcome with a simple modification in the original CNN model. This consists of changing the non-linear feedback loop of the cell by a linear one (see Fig. 1). Thus, we reach the alternative model proposed in this paper, whose analytic expressions are given by the differential equations showed in expression (4) and the ordinary difference equation (5), derived from the forward Euler form.