Developments in Fuzzy Sets, Intuitionistic Fuzzy Sets, Generalized Nets and Related Topics. Volume I: Foundations

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Generalized net model of impulsive delay cellular neural networks

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Abstract

A review of the generalized net models of different types of neural networks is given. A generalized net model of impulsive delay cellular neural networks is constructed.

1 Introduction

In [11] the problem for representation of the separate types of Neural Networks (NNs) by Generalized Net (GN, see [5, 10, 12, 36]) is formulated. The first GN-models that represent the algorithms for training of a NN are given in [7, 13, 14,

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15, 21, 22, 23, 24, 25, 28, 29, 30, 31, 32, 33, 35, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47].

Here, a GN model of impulsive cellular NNs with time delays will be constructed.

Chua and Yang [19, 20] proposed a novel class of information-processing system called Cellular NNs (CNNs) in 1988. Like NNs, it is a large-scale nonlinear analog circuit, which processes signals in real time. Like cellular automata [51] it is made of a massive aggregate of regularly spaced circuit clones, called cells, which communicate with each other directly only through its nearest neighbours. Each cell is made of a linear capacitor, a nonlinear voltage-controlled current source, and a few resistive linear circuit elements.

The key features of NNs are asynchronous parallel processing and global interaction of network elements. Impressive applications of NNs have been proposed for various fields such as optimization, linear and nonlinear programming, associative memory, pattern recognition and computer vision. For the circuit diagram and connection pattern implementing the CNN, one can refer to [19]. The CNN can be applied in signal processing and can also be used to solve some image processing and pattern recognition problems [20]. However, it is necessary to solve some dynamic image processing and pattern recognition problems by using Delayed CNNs (DCNNs) [9, 16, 17, 18, 27]. The study of the stability of CNN and DCNN is known to be an important problem in theory and applications.

On the other hand, the state of electronic networks is often a subject to instantaneous perturbations and experience abrupt changes at certain instants, which may be caused by switching phenomena, frequency change or other sudden noise, that exhibits impulsive effects [2, 8, 26]. For instance, according to Arbib [8] and Haykin [26], when a stimul from the body or the external environment is received by receptors the electrical impulses will be conveyed to the NN and impulsive effects arise naturally in the net.

Therefore, NN model with delay and impulsive effects should more accurately to describe the evolutionary process of the systems. Since delays and impulses can affect the dynamical behaviour of the system, it is necessary to investigate both delay and impulsive effects on the stability of NNs [1, 34, 48, 49, 50]. Such a generalization of the DCNN notion should enable us to study different types of classical problems as well as to “Control” the solvability of the DCNN (without impulses).

2 On the Impulsive Delay Cellular Neural Networks (IDCNNs)

Let R^n denote the n-dimensional Euclidean space, and let $||x|| = \sum_{i=1}^{n} |x_i|$ define the norm of $x \in R^n$. Let $R_+ = [0, \infty)$ and $t_0 \in R_+$.

We consider the following impulsive DCNNs

$$\dot{x}_i(t) = -c_i x_i(t) + \sum_{j=1}^{n} a_{ij} f_j(x_j(t)) + \sum_{j=1}^{n} b_{ij} f_j(x_j(t - \tau_j(t))) + I_i,$$

$$t \neq t_k, \ t > t_0, \tag{2.1}$$

$$\Delta x_i(t_k) = x_i(t_k + 0) - x_i(t_k) = P_{ik}(x_i(t_k)), \ k = 1, 2, ..., \tag{2.2}$$

$i = 1, 2, ..., n$, where n corresponds to the number‘ of units in a NN; $x_i(t)$ corresponds to the state of the i-th unit at time t; $f_j(x_j(t))$ denotes the output of the j-th unit at time t. Further, a_{ij}, b_{ij}, I_i, c_i are constants, a_{ij} denotes the strength of the j-th unit on the i-th unit at time t, b_{ij} denotes the strength of the j-th unit on the i-th unit at time $t - \tau_j(t)$, I_i denotes the external bias on the i-th unit, $\tau_j(t)$ corresponds to the transmission delay along the axon of the j-th unit and satisfies $0 \leq \tau_j(t) \leq \tau$ ($\tau = constant$), c_i represents the rate with which the i-th unit will reset its potential to the resting state in isolation when disconnected from the network and external inputs, t_k, $k = 1, 2, ...$ are the moments of impulsive perturbations and satisfy $t_0 < t_1 < t_2 < ...$ and $\lim_{k \to \infty} t_k = \infty$; $x_i(t_k - 0) = x_i(t_k)$ and $x_i(t_k + 0)$ are the states of the i-th unit before and after the impulsive perturbation at t_k, respectively; and $P_{ik}(x_i(t_k))$ represents the abrupt change of the state $x_i(t)$ at the impulsive moment t_k.

Let $J \subset R$ be an interval. Define the following class of functions:

$$CB[J, R^n] = \{\sigma \ : \ \sigma \in C[J, R^n] \ \& \ \sigma(t) \text{ is bounded on } J\}.$$

Let $\varphi \in CB[[-\tau, 0], R^n]$. Denote by $x(t) = x(t; t_0, \varphi), \ x \in R^n$ the solution of system (2.1), (2.2), satisfying the initial condition:

$$\begin{cases} x(t; t_0, \varphi) = \varphi(t - t_0), \ t_0 - \tau \ \leq \ t \leq \ t_0, \\ x(t_0 + 0; t_0, \varphi) = \varphi(0). \end{cases} \tag{2.3}$$

The solution $x(t) = x(t; t_0, \varphi) = (x_1(t; t_0, \varphi), ..., x_n(t; t_0, \varphi))^T$ of problem (2.1), (2.2), (2.3) is a piecewise continuous function with points of discontinuity of the first kind t_k $k = 1, 2, ...$, where it is continuous from the left, i.e. the following relations are valid

$$x_i(t_k - 0) = x_i(t_k), \quad k = 1, 2, ...,$$

$$x_i(t_k + 0) = x_i(t_k) + P_{ik}(x_i(t_k)), \; t_k > t_0.$$

We note that by integrating (2.1) in the interval $(t_0, t_1]$ we obtain

$$x_i(t) = x_i(t_0 + 0) + \int_{t_0}^{t} F_i(s)\, ds, \quad t \in (t_0, t_1],$$

where

$$F_i(t) = -c_i x_i(t) + \sum_{j=1}^{n} a_{ij} f_j\left(x_j(t)\right) + \sum_{j=1}^{n} b_{ij} f_j\left(x_j(t - \tau_j(t))\right) + I_i,$$

$1 \le i \le n.$

From (2.2) we have that

$$x_i(t_1 + 0) = x_i(t_1) + P_{i1}(x_i(t_1)), \quad 1 \le i \le n.$$

We now integrate (2.1) in the interval $(t_1, t_2]$ and we obtain

$$x_i(t) = x_i(t_1 + 0) + \int_{t_1}^{t} F_i(s)\, ds, \quad t \in (t_1, t_2].$$

By similar arguments we can obtain that

$$x_i(t) = x_i(t_k + 0) + \int_{t_k}^{t} F_i(s)\, ds, \quad t \in (t_k, t_{k+1}].$$

for $1 \le i \le n$, $k = 1, 2, ...$

Especially, a constant point $x^* \in R^n$, $x^* = (x_1^*, x_2^*, ..., x_n^*)^T$ is called an equilibrium point of (2.1), (2.2) if $x^* = x^*(t; t_0, x^*)$ is a solution of (2.1), (2.2), (2.3) such that

$$c_i x_i^* = \sum_{j=1}^{n} a_{ij} f_j(x_j^*) + \sum_{j=1}^{n} b_{ij} f_j\left(x_j^*\right) + I_i,$$

$$P_{ik}(x_i^*) = 0, \quad i = 1, 2, ..., n, \;\; k = 1, 2, ...$$

Let $||\varphi||_\tau = \max_{s\in[t_0-\tau,t_0]} ||\varphi(t-t_0)||$ be the norm of the function $\varphi \in CB[[-\tau,0],R^n]$.

Definition 2.1. The equilibrium $x^* = col(x_1^*, x_2^*, ..., x_n^*)$ of system (2.1), (2.2) is said to be *globally exponentially stable*, if there exists a constant $\gamma > 0$ such that

$$||x(t;t_0,\varphi) - x^*|| \le e^{-\gamma(t-t_0)}||\varphi - x^*||_\tau,\ t \ge t_0.$$

3 Generalized net model

Here we shall construct a GN model (see Fig. 1) of the above described type of NNs. It contains 5 transitions, 13 places and 5 types of tokens. One of them – token δ stays permanently in place l_2 with initial characteristics

"ordered set of all values of the initial function φ or a rule for calculating the values of φ, current value of delay at each moment",

for token δ, and the other token in place l_8 with current characteristics

"ordered set of all values of the moments t_k and the functions P_{ik} or a rule for calculating the values of t_k and P_{ik}, current value of the t_k and P_{ik}".

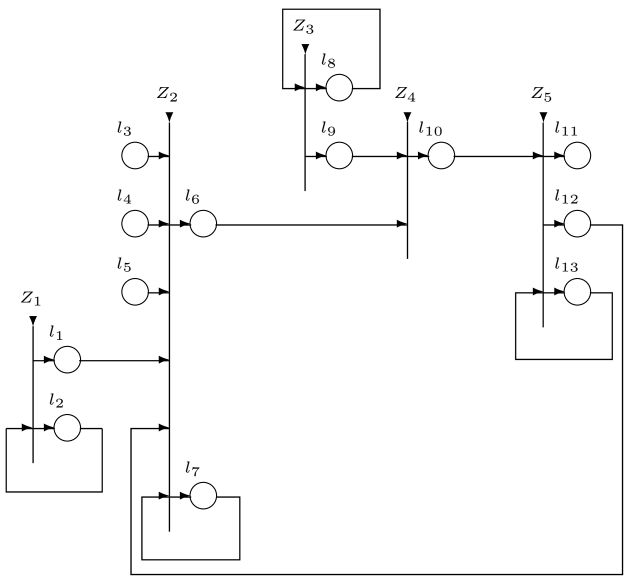

Fig. 1.

In the first time-moment of the GN functioning, tokens α, β, γ enter places l_3, l_4, l_5, respectively with initial characteristics:

• for token α:

"topological structure of the IDCNN; ε",

where ε is a constant corresponding to $e^{-\gamma(t-t_0)}||\varphi - x^*||_\tau$;

• for token β:

"initial values of the inputs of the IDCNN and the components x_i^* of the equilibrium x^*";

• for token γ:

"weight coefficients a_i, b_i, coefficients c_i and I_i".

These tokens must be enumerated by $\alpha_i, \beta_i, \gamma_i$, where i is their current number of entering the GN, but for brevity in this and in the next cases, we will omit the indices.

$$Z_1 =< \{l_2\}, \{l_1, l_2\}, \begin{array}{c|cc} & l_1 & l_2 \\ \hline l_2 & W_{2,1} & true \end{array} >,$$

where

$$W_{2,1} = \text{"}\overline{c}(l_3, TIME) + \overline{c}(l_4, TIME) + \overline{c}(l_5, TIME) + \overline{c}(l_{12}, TIME) > 0\text{"}$$

(where $\overline{c}(l, TIME)$ is the number of tokens in place l in the current moment $TIME$), if we like the model to calculate delays in each step, or $W_{2,1}$ is a condition that determine the time-moments in which the moment $TIME - DELAY$.

Token δ splits to two tokens – token δ that continues to stay in place l_2 and token δ' that enters place l_1 with characteristic

"current value of a delay".

$$Z_2 =< \{l_1, l_3, l_4, l_5, l_7, l_{12}\}, \{l_6, l_7\}, \begin{array}{c|cc} & l_6 & l_7 \\ \hline l_1 & true & true \\ l_3 & true & true \\ l_4 & true & true \\ l_5 & true & true \\ l_7 & false & true \\ l_{12} & true & false \end{array} > .$$

Tokens $\alpha, \beta, \gamma, \delta'$ enter place l_7 and there they are collected, generating a protocol of the process. On the other hand, all these tokens split to two tokens

– the above mentioned ones and tokens $\alpha', \beta', \gamma', \delta''$ that enter place l_6, where they merge in one token (let us mark it by α). This token also unites with the α-token when it enters place l_6 from place l_{12}. The new α-token obtains as a new characteristic

$$\text{“the } i\text{-th component } x_i(t) = x_i(t_0 + 0) + \int_{t_0}^{t} F_i(s)\,ds,, \quad t \in (t_0, t_1]\text{”.}$$

$$Z_3 =< \{l_8\}, \{l_8, l_9\}, \begin{array}{c|cc} & l_8 & l_9 \\ \hline l_8 & true & W_{8,9} \end{array} >,$$

where
$W_{8,9} =$ “$\overline{c}(l_6, TIME) > 0$”.

If we like the model to calculate t_k and P_{ik} in each step, or $W_{8,9}$, then the condition determines the time-moments in which the solution is subject to instantaneous perturbations at moment t_k with magnitute P_{ik}.

Token ε splits to two tokens – ε that continues staying in place l_8, and token ε' that enters place l_9 with a characteristic

“current value of the function P_{ik}”.

$$Z_4 =< \{l_6, l_9\}, \{l_{10}\}, \begin{array}{c|c} & l_{10} \\ \hline l_6 & true \\ l_9 & true \end{array} > .$$

The α-token and the ε'-tokens unite under the name α in place l_{10} with characteristic

“the i-th component after the impulse effect at t_k:

$$x_i(t_k + 0) = x_i(t_k) + P_{ik}(x_i(t_k))\text{”}.$$

$$Z_5 =< \{l_{10}, l_{13}\}, \{l_{11}, l_{12}, l_{13}\}, \begin{array}{c|ccc} & l_{11} & l_{12} & l_{13} \\ \hline l_{10} & W_{10,11} & W_{10,12} & true \\ l_{13} & false & false & true \end{array} >,$$

where the forms of the predicates will be discussed below.

Each α-token from place l_{10} splits and one of the new tokens (let us mark it by α^*) enters place l_{13} with characteristic

$$x_s^\alpha = \text{“}x_s^\alpha(t; t_0, \varphi) = (x_{s1}^\alpha(t; t_0, \varphi), ..., x_{sn}^\alpha(t; t_0, \varphi))^T,$$

where s is the current number of the α^*-token and

$$x_{si}^{\alpha}(t) = x_{si}^{\alpha}(t_k + 0) + \int_{t_k}^{t} F_{si}^{\alpha}(s)\, ds, \quad t \in (t_k, t_{k+1}],$$

$i = 1, 2, ..., n$, $k = 1, 2, ...$ These α-tokens are collected in place l_{13} and their characteristics are used in the process of the calculatiuon of the truth-values of the predicates $W_{10,11}$ and $W_{10,12}$. The second token, gererated by the current α-token, is directed to place l_{11} or l_{12} with respect to the truth-values of predicates $W_{10,11}$ and $W_{10,12}$, that have the forms:
$W_{10,11} =$ "$||x_s^{\alpha} - x^*|| < \varepsilon$",
where ε is the constant, given as an initial characteristic of the current α-token, and
$W_{10,12} = \neg W_{10,11}$,
where $\neg P$ is the negation of predicate P.

When $W_{10,12}$ has truth-value $true$, i.e., when

$$||x_s^{\alpha} - x^*|| \geq \varepsilon,$$

the α-token enters place l_{12} without a new characteristic and the procedure repeats.

4 Conclusion

The so constructed GN-model gives us possibility not only to describe the process of functioning of a IDNN, but we can use it for organizing the simultaneous work of some (of course, finite number) of NNs. If we construct GN-models of some NNs, these models can exchange values, calculated in their frameworks, search for optimal or extremal values among these, calculated in them, and investigate the global exponential stability of the equilibrium points.

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The papers presented in this Volume 2 constitute a collection of contributions, both of a foundational and applied type, by both well-known experts and young researchers in various fields of broadly perceived intelligent systems.

It may be viewed as a result of fruitful discussions held during the Eighth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2009) organized in Warsaw on October 16, 2009 by the Systems Research Institute, Polish Academy of Sciences, in Warsaw, Poland, Centre for Biomedical Engineering, Bulgarian Academy of Sciences in Sofia, Bulgaria, and WIT – Warsaw School of Information Technology in Warsaw, Poland, and co-organized by: the Matej Bel University, Banska Bistrica, Slovakia, Universidad Publica de Navarra, Pamplona, Spain, Universidade de Tras-Os-Montes e Alto Douro, Vila Real, Portugal, and the University of Westminster, Harrow, UK:

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The Eighth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2009) has been meant to commence a new series of scientific events primarily focused on new developments in foundations and applications of intuitionistic fuzzy sets and generalized nets pioneered by Professor Krassimir T. Atanassov. Moreover, other topics related to broadly perceived representation and processing of uncertain and imprecise information and intelligent systems are discussed.

We hope that a collection of main contributions presented at the Workshop, completed with many papers by leading experts who have not been able to participate, will provide a source of much needed information on recent trends in the topics considered.

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