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HARDWARE IMPLEMENTATION DESIGN IN LABVIEW OF FUZZY ART BASED PARTIALLY PARALLEL CLUSTERING SYSTEM

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A hardware implementation design of Fuzzy Adaptive Resonance Theory (ART) based partially parallel clustering system in FPGA reconfigurable computing architecture is presented. The category choice and resonance is proposed to perform in parallel. In particular, it is suggested to compute in parallel the choice functions. Moreover, the KWTA neural circuit based rank-order filters (ROFs) are proposed to use for computing largest values of the choice functions instead of the WTA unit. In addition, the vigilance condition is also suggested to verify in parallel. In this way, repeating sequential processes for the category choice and resonance can be replaced with one parallel process. This allows to reduce a computational time required for the clustering.

Keywords: Fuzzy Adaptive Resonance Theory, reconfigurable computing architecture, hardware description language, rank-order filter.

ПРОЕКТ СХЕМОТЕХНІЧНОЇ РЕАЛІЗАЦІЇ В LABVIEW ЧАСТКОВО ПАРАЛЕЛЬНОЇ СИСТЕМИ КЛАСТЕРИЗАЦІЇ, ЯКА ОСНОВАНА НА НЕЧІТКІЙ ТЕОРІЇ АДАПТИВНОГО РЕЗОНАНСУ

Наведено проект схемотехнічної реалізації частково паралельної системи кластеризації, яка основана на нечіткій теорії адаптивного резонансу (ТАР), на програмованих логічних інтегральних схемах (ПЛІС) із реконфігурованою обчислювальною архітектурою. Вибирати категорію та резонанс пропонується паралельно, зокрема паралельно обчислювати функції вибору. Крім цього, для обчислення найбільших значень функцій вибору замість Winner-Takes-All (WTA) комірки пропонується використовувати паралельні ранжувальні фільтри (РФ), що ґрунтуються на нейронних схемах типу K-Winners-Take-All (KWTA). На додаток, так звану умову подібності також пропонується провіряти у паралельному режимі. Отже, повторювальні послідовні процеси вибору категорії і резонансу можна замінити на один паралельний процес. Це дасть змогу скоротити час обчислень, необхідний для кластеризації.

Ключові слова: нечітка теорія адаптивного резонансу, реконфігурована обчислювальна архітектура, мова опису апаратури, ранжувальний фільтр.

Introduction

Adaptive Resonance Theory (ART) is a cognitive and neural theory of how the brain autonomously learns to categorize, recognize, and predict objects and events in a changing world. There have been developed many ART based unsupervised learning methods as well as supervised learning methods. Numerous variants of ART algorithms have been used in various engineering and technological applications. However, the processing time can be too high to satisfy real-time demands [1].

The Fuzzy ART network consists of two layers of computing cells or neurons F_1 and F_2, and a vigilance subsystem controlled by an adjustable vigilance parameter $\rho \in [0,1]$ (Fig. 1). Layer F_1 is the input

layer composed of N input cells. Each input cell receives a component $I_i \in [0,1]$, $i=1,\ldots,N$ of the input vector $I=(I_1,\ldots,I_N)$. Layer F_2 is the category layer. It is composed of M cells, each one representing a possible category. Each category cell receives an input T_j, $j=1,\ldots,N$. Each ith neuron of F_1 layer is connected to each jth neuron of F_2 layer by a synaptic connection of weight z_{ij}^{bu}. Each jth neuron of F_2 layer is connected to each ith neuron of F_1 layer by a synaptic connection of strength z_{ji}^{td} . In the Fuzzy ART $z_{ij}^{bu}= z_{ji}^{td}$. Consequently, from now we will refer to the weights as $z_{ij}= z_{ij}^{bu} =z_{ji}^{td}$.

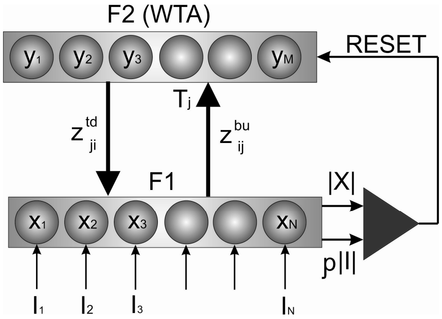

Fig. 1. Topological structure of the Fuzzy ART architecture

The flow diagram of the Fuzzy ART operation is presented in Fig. 2. Initially, all the interconnection weights z_{ij} are set to '1'. When an input vector $I=(I_1,\ldots,I_N)$ is applied to the system, each category cell of F_1 layer receives a component $I_i \in [0,1]$. Then each category cell of F_2 layer receives an input T_j, $i=1,\ldots,N$ which is a measurement of the similarity between the input pattern I and the weight template $z_j=(z_{1j}, \ldots, z_{Nj})$ stored in category *j*.

$$T_j = \frac{|I \wedge z_j|}{\alpha + |z_j|} \tag{1}$$

where $\wedge$ is a fuzzy MIN operator defined by $(X \wedge Y)_I = min(X_i, Y_i)$, $|X|$ is an i_1 norm $|X| = \sum_{i=1}^{N} |X_i|$, and α is a positive parameter called 'choice parameter'. The *j*-th F_2 cell provides an output y_j which is '1' if this cell is receiving the largest T_j input and '0' otherwise. This way, the F_2 layer (which acts as Winner-Takes-All (WTA)) selects the category *J* whose stored template z_j most closely resembles input pattern *I* according to the similarity criterion (1).

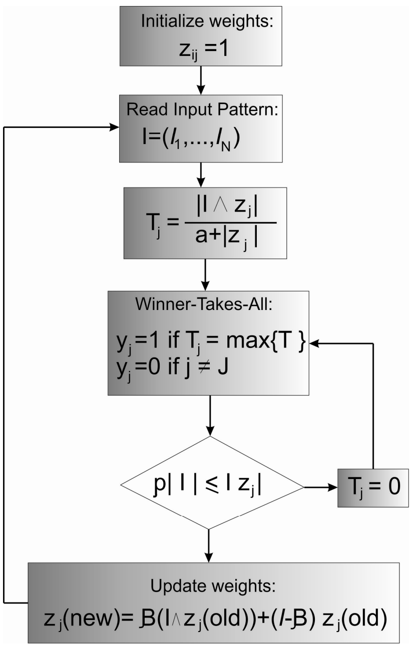

Fig. 2. Flow diagram of the Fuzzy ART operation

For the winning category *J*, the vigilance subsystem checks the condition

$$\rho \mid I \mid \leq \mid I \wedge z_j \mid, \tag{2}$$

where ρ is a vigilance parameter. If condition (2) is not true, category *J* is discarded by forcing $T_j=0$. Layer F_2 will again select the category with maximum T_j, $i=1,\ldots,N$ and the vigilance criterion (2) will be checked again. This search process continues until layer F_2 finds a winning category which fulfills the vigilance criterion (2).

When a category *J* that meets the vigilance condition (2) is activated, its weights z_j are updated according to the rule

$$z_j(new) = \beta(I \wedge z_j(old)) + (1-\beta)z_j(old), \tag{3}$$

where $\beta \in [0,1]$ is the learning rate parameter.

Partial parallelization of fuzzy adaptive resonance theory based clustering using rank-order filters

The category choice of the Fuzzy ART is performed by sequential computing choice functions of the cluster. Moreover, this step requires sequential recursive identification those of the functions which have largest values satisfying a vigilance condition. Furthermore, vigilance condition verification is also fulfilled sequentially. This can lead to time consuming process of clustering especially for large data sets [1].

In this paper, to increase a speed of the clustering in the Fuzzy ART, the category choice and resonance is proposed to perform in parallel. In particular, it is suggested to fulfill parallel computing of the choice functions. Moreover, the K-Winners-Take-All (KWTA) neural circuit based rank-order filters (ROFs) are proposed to use for computing largest values of the choice functions instead of the WTA unit [2]. In addition, the vigilance condition is also suggested to verify in parallel. In this way, repeating sequential processes for the category choice and resonance can be replaced with one parallel process. This allows to provide a reducing of computational time required for the clustering.

The partially parallel clustering system based on Fuzzy ART can be implemented in an up-to-date hardware (Fig. 3) [3–6]. In such hardware signals are received through the input system unit Simulate Signal which is capable to operate in two modes: internal signal generation and acception of signals from the outside. Then the signals are fed to the input Summation block the output of which is connected to the MathScript element that describes the function of selecting the maximum value by the high-level language. After processing input signals, all inputs summed up on the general combiner systems and MathScript element whose output signals are passed through the converter and displayed on an Waveform Graph. All operations are combined in a cyclic structure whose parameters are set in the project properties. In such the system all structural elements are integrated in one subproject. The design contains summers, multipliers, integrators, switchers and external power sources which are described in top entity of the project. The system uses MathScript Integrator Technology and summation functions are implemented as a subsystem based on the shift-registers and trigger elements. Since the system should operate in a real-time, arithmetical tasks are fed into mathscript subblocks that are being parts of Softprocessor technology realized in appropriate environment.

The software platform of the system allows two levels of definition of the logic functions. In particular, the first level is defined by an electric schematic diagram, second level is described by hardware description languages [6]. The system uses hardware-defined graphical language. Each its functional block stored in visual HDL-blocks is realized by Verilog language. A data scalability and real-time signal processing are provided. The input-output block possesses communication possibilities outside of the system. Programmable interconnection block connects the different levels of the system and allows them to communicate each with other. All the modules of the system are compiled for performing Analysis and Synthesis check, Place and Route check, Assembler check and Classic Timer Analyzer check. The input signals are being preprocessed using a standard STM8 microcontroller unit and simulated using hardware potentiometer block. Since the magnitude of the signal level should not exceed the level of the applied voltage, there is realized a voltage limiter that runs the algorithm of voltage divider. Data transaction are implemented using serial interface protocol RS-232.

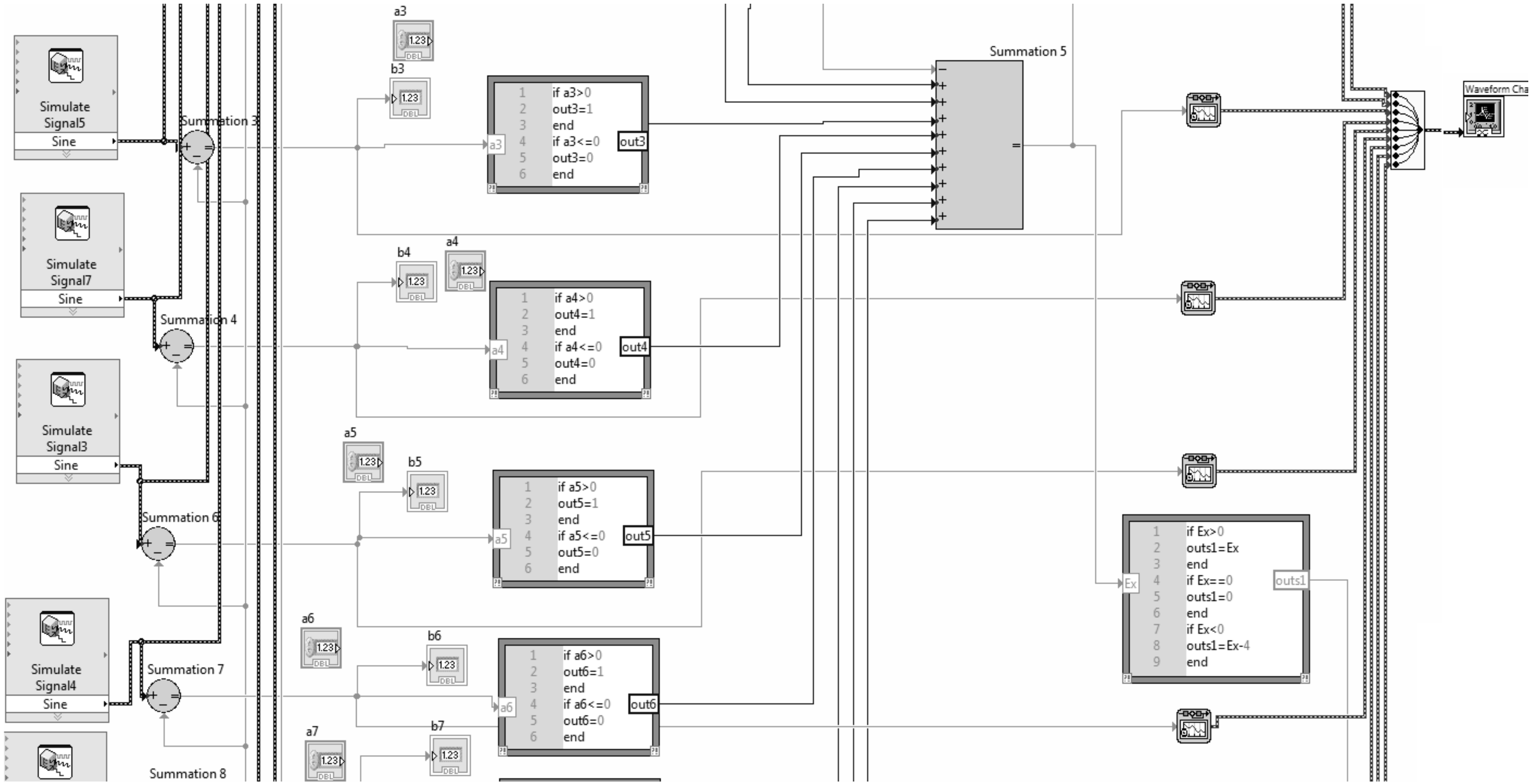

Fig. 3. Hardware implementation design of partially parallel clustering system

Conclusion

A hardware implementation design of Fuzzy ART based partially parallel clustering system by using FPGA is presented. The category choice and resonance is suggested to perform in parallel. As a result, a possibility of replacing repeating sequential processes for the category choice and resonance with one parallel process is appeared. This provides a possibility to decrease a computational time necessary for the clustering. The clustering system is implemented by using a virtual instrumentation environment. The presented system is suitable for different applications.

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