CNN Computer for High Speed Visual Inspection.

Rodrigo Montúfar-Chaveznava*, Domingo Guinea,
Maria C. Garcia-Alegre and Victor M. Preciado.

Instituto de Automática Industrial – CSIC
28500 Arganda del Rey. Madrid. SPAIN

ABSTRACT

An image entails a huge amount of data and information. For this reason, image synthesis and analysis by computer systems requires a high processing time. This represents a handicap in systems where real time processing or an immediate interpretation is demanded as in visual inspection industrial applications. Present work, introduces a computer architecture for the construction of a compact real-time system for high speed visual inspection. The vision system is essentially a Cellular Neural Network Computer (CNN-C) basically composed of a Cellular Neural Network Universal Machine (CNN-UM), an analog memory, an imager and a control unit with mixed-signal properties. This prototype has some limitations, but represents the first approximation of a new kind of systems for visual inspection. The CNN-C prototype will be tested in visual inspection of paper, metal and polymer surfaces. Besides the CNN-C can be used in many other image processing tasks, such as coding, singularity detection or multiresolution representation.

Keywords: Cellular Neural Networks, High Speed Visual Inspection, Machine Vision, Computer Architecture.

1. INTRODUCTION

At present, image processing has become an elemental tool for almost every scientific or industrial field where, in similarity to the human being, vision and scene interpretation is essential. But as an image represents a high amount of data and information, its synthesis and analysis by computer systems requires high processing time, and this point is a drawback when dealing with industrial applications that need a short time interpretation to derive a control action. Present work proposes the construction of a real-time system for image processing, a Cellular Neural Network Computer (CNN-C). This CNN-C is composed basically by a CNN Universal Machine (CNN-UM), an analog memory, an imager and a control unit. As a prototype it has some limitations, but represents the first approximation of a new kind of CNN-C, intended for high speed visual inspection. In spite of being designed to solve high speed visual inspection tasks, its application domain can be extended to many other areas as are medicine, agriculture, environmental sciences and so on.

Traditionally, the vision process involves the following sequence: image acquisition by an analog media (such as an imager) as analog data; analog to digital data conversion and computer processing to make a decision and perform an action. It can be noticed that there is a similarity between the artificial vision process and the human being vision process. The imager and the eyes have the same function: sense the scene, capture the image. The image sensed should be submitted to an interpretation o translation process before to go to the brain. In humans such conversion corresponds to nerves that translate the image sensed to electrical signals. Finally, the brain makes a decision according to the perception and performs or commands an action. Such sequence of processes defines the behavior in humans. Figure 1, shows the similarity between the human and the CNN-C.

Almost all image processes such as segmentation, filtering, singularity detection, coding and enhancement are performed by a convolution operation between image data and a specific kernel. Then, the overall operation demands certain time, and the principal time consumers are the data conversion and the manipulation tasks. Some times the image processing can also be very high time consuming, but this strongly depends on the process to be performed.

* Correspondence: e-mail: montufar@iai.csic.es; Telephone: +34 918711900; Fax: +34 918717050

Specialized tasks need very low time consumption, then, considering that a CNN-UM can perform the image processing without the necessity of data conversion, the inclusion of such element would be required in the design. Furthermore, the introduction of an analog memory in a CNN-C will aid to get a better performance. On the other hand, as before mentioned, many image processes involve a convolution operation. In images, such convolution is time-consuming, due to the 2-D nature of images that demands the use of 2-D kernels. This problem use to be solved by separable 1-D filters, or Quadrature Mirror filters, making a two steps process: first along the rows and then along the columns. The CNN-C will permit to perform 2-D operations in only one step, and open the possibility to employ a wide variety of kernels, not only the separable ones.

Final aim for the CNN-C prototype would be its use in visual inspection tasks related to paper, metal and polymers surfaces on line production.

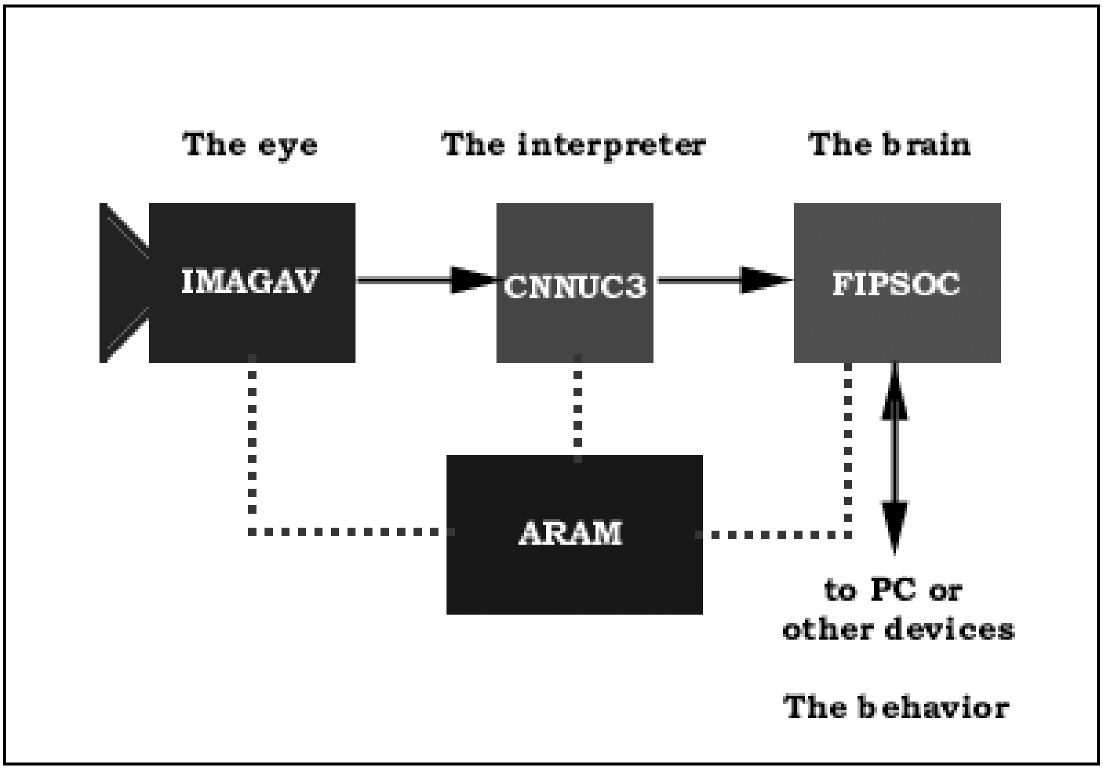

Figure 1. Similarities between human and CNN-C visual processing

2. INDUSTRIAL VISUAL INSPECTION

The knowledge on the quality of a surface is a major issue as it determines the value of the whole product, extensive surface inspection for mass production of strip products, is highly demanded in industrial applications. Specially, both the steel and paper manufacturer under the pressure of customers demands of high quality products are asking for solutions that keeps at the same time low margins. Nowadays, automatic inspection of surfaces is still a challenge for visual systems, due to spatial and temporal restrictions in image acquisition and processing of current visual systems.

Actually, the performance capabilities of developed systems are not so much the result of the use of digital video technology and standard PCs, but rather the result of the sophisticated software generated by several hundred of scientists and programmers.

Taking all these premises into account, present work proposes the design of a CNN Computer as an artificial visual system for high speed real time inspection in continuous line production, where hardware technology plays the principal role instead of software development, in order to obtain the high performances demanded by industry.

During inspection, time restrictions in acquisition and processing, inherent to all conventional camera-computer systems will be circumvented by means of arrays of sensors and analogic processors on a network of CNNs. The CNN-C, able to offer high speed local control of both position and illuminant, can be integrated in the on-line production systems for the on-line detection of defects.

Additionally, the expected results during the inspection can be improved by adding a specific luminance system or strategy of illumination to the overall system. For example, selective illumination with laser of different frequencies will allow a high resolution local spectrophotometry as a complementary source to identify the origin or the cause of the detected defects. The objective of the proposed system will be the on-line defect detection to prevent further on progressing of the metal or paper damaged sheets on the production system.

All developed programs required to accomplish the visual inspection tasks would be tested with a wide set of examples by using learning algorithms in order to obtain high flexibility and robustness in defects pattern recognition. Fuzzy logic based models can also be tested, and evolutionary algorithms employed in the search for the most appropriate masks for the CNNs, according to the universe of examples of any particular application.

There is a second stage devoted to set up the more adequate experimental conditions for each application, as are optical parameters, position and degrees of freedom, illumination, etc. These parameters would permit the evaluation of the developed technology from the point of view of the specific industrial domain establishing its practical and economical suitability for its integration in the production line as an automated visual inspection system.

3. THE CNN PARADIGM.

The CNN is an analog parallel-computing paradigm defined in space, and characterized by the locality of connections between processing elements such as cells or neurons. Such systems are best suited for local and diffusion-solvable problems. A CNN representation is shown in Figure 2.

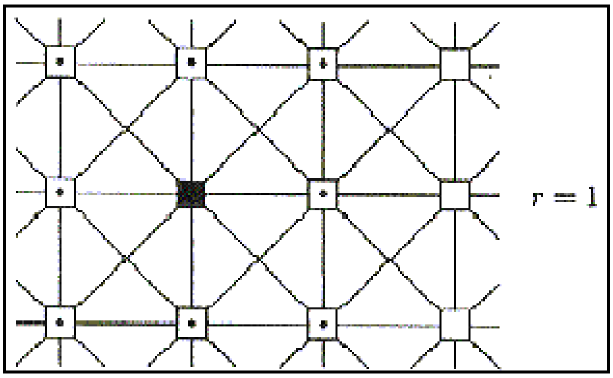

Figure 2. CNN Representation

By definition[1] a CNN is a 2-, 3-, or n-dimensional array of identical dynamical systems, called cells, which satisfies two properties: most interactions are local within a finite radius *r*, and all state variables are continuous valued signals. A template specifies the interaction between each cell and all its neighbor cells in terms of their input, state, and output variables.

Additionally, next considerations have to be taken into account:

1. Each cell is identified by 2, 3 or *n* integers (*i*, *j*, *k*… *n*), i.e., the space variable is always discretized.

2. The time variable *t* may be continuous or discrete.

3. The interconnection effect represented by the cloning template may be a nonlinear function of the state ***x***, output ***y***, and input ***u*** of each cell, within the neighborhood N_r of radius *r*, as well as that of the time *t*. In general, the cloning template is not space invariant.

4. The dynamical system is governed uniquely by an *evolution law* such that given $\mathbf{x}(t_0)$ and $\mathbf{u}(t)$ for all $t \geq t_0$ and given the signals stored in the delay lines at $t = t_0$ (if there is any), $\mathbf{x}(t)$ is uniquely determined for all $t \geq t_0$. This includes the boundary conditions.

5. Occasionally, the dynamical system and/or the interconnections may be perturbed by some noise sources of known statistics.

Then, there exist many choices for the array grid, the cell dynamics, the interaction, and the mode of operation, etc. A CNN classification can be found in [1].

From [2], the general form of the cell dynamical equations may be stated as follows:

$$\tau \frac{dx^c}{dt} = -g(x^c) + \sum_{d \in N_r(c)} A_d y^d + \sum_{d \in N_r(c)} B_d u^d + D_A + D_B \tag{1}$$

We can refer to neighbors in $N_r(c)$ by their numeric assignment.

4. THE CNN-C PROTOTYPE

As mentioned in the introduction, the CNN-C is essentially composed by four basic elements: an imager, a CNN-UM, an ARAM and a control unit such as a microcontroller or a microprocessor. Figure 3 shows the schematic of the proposed CNN-C.

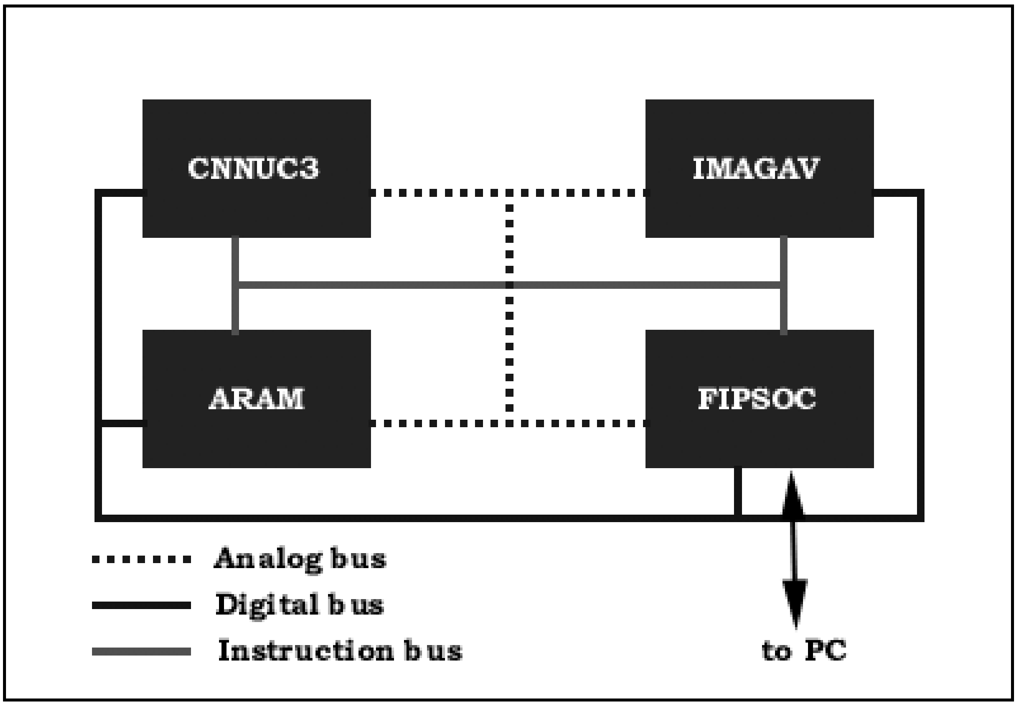

Figure 3. The CNN Computer Prototype

The main characteristics of the basic elements of the proposed CNN-C are described below:

CNN-UM: The CNNUC3[2] will be integrated in the CNN-C prototype, it is a Cellular Neural Network Universal Chip designed to work with 3.3 V power supplies whereas the power consumption will remain around 0.8 W. Every cell includes circuitry for CNN processing, binary and gray scaled images storage, login operations among binary images and the necessary configuration circuitry for electrical I/O and control of the different operations. Every cell in the 64×64 array includes the necessary circuitry to implement a FSR CNN model. Neighborhood radius is one. Feedback and control templates include weights for all the nine adjacent neighbors. The offset or bias term is modeled by two summands. The central element of the feedback template (self-feedback) used in this prototype must be reduced in one unit with respect to the value that would be used with the original Chua-Yang model[1].

Imager: The imager considered in the model is the IMAGAV[3], which is an imager prototype intended for averaging operations. It includes a 64×64 array of identical pixels as well as the selection, control and output circuitry of the array. Its main functionality is image acquisition and pixel averaging. IMAGAV includes passive pixels in its design, which integrate the photo-generated charge; therefore, precharge and exposition processes are needed before reading the acquired image. The pixel includes also an active pixel output, although it is not optimized and its output rate is lower than the passive pixel structure. The prototype includes random access to all the pixels by selecting the row and column. The read out process can be done pixel by pixel or directly reading a group of pixels, giving the averaged illumination value at the output. Due to its design, the read out process is destructive and a new precharge and exposition is needed before the signal is again available.

ARAM: The AM8192C[4] Analog RAM prototype chip is considered into the CNN-C design; it is composed of a 32×256 analog memory cells array consisting in a capacitor, a pass transistor and some local logic for address decoding. They are arranged into 32 Sample and Hold lines with 256 capacitors each. Random access to any memory location is done coding the proper address. In order to avoid massive capacitor selection per row at same time, which seriously degrades the operation, a global memory access strobe leaves a tunable guard time for address code to change. I/O analog data transmission is done either by a 16-line wide I/O bus or a serial I/O channel. The I/O MUX/DEMUX with the help of the row selection decoder scans the 32 array data lines.

Control Unit: The CNN-C brain is reserved for the FIPSOC[5] system, which is a new approach to a system prototyping for mixed signal applications. It consists of a mixed signal device with on-chip microprocessor, suitable user-friendly CAD tools to program it and a set of library macros and applications to provide an easy path to migration to ASIC when necessary. The chip comprises a RAM based, a multicontext dynamically reconfigurable lookup table section and includes some large granularity logic cells targeted for synthesis programs, it also includes programmable analog blocks with configurable interconnectivity and an optimized interface to the on-chip 8051 microprocessor core. The microprocessor can read and write both the configuration and the internal signals (digital and analog) while in operation, providing a powerful workbench for real time probing, hardware-software interaction and application based on dynamic reconfiguration (two configurations can be stored so the user can switch between them by a simple microprocessor command). The CAD design flow includes mixed signal design specification, simulation, automatic technology mapping, device programming, and real time emulation (probing of internal signals), so the user can work at system level with microprocessor code and mixed-signal hardware using an integrated design tool. Finally, library macros are being developed to support typical user applications and to provide an immediate way to migrate the application to ASIC after prototyping.

We can see the basic elements considered for CNN-C construction are all prototypes, it means the complete construction could carry some complications, however, at the end, this CNN-C could be a solution for many applications where, as mentioned above, time consumption is critical.

The principal characteristics and considerations for this prototype since a functional point of view are:

1. The retina area or size of image acquired is 64×64 pixels. The acquired image can be averaged in fly if needed because of the IMAGAV characteristics

2. The CNNUC3 works over a 64×64 cells array.

3. The CNN equation that models the CNNUC3 chip is:

$$\tau \frac{dx^c}{dt} = -g(x^c) + \sum_{d=1}^{9} A_d y^d + \sum_{d=1}^{9} B_d u^d + D_A + D_B \tag{2}$$

where
$$g(x^c) = \begin{cases} -\infty, x^c < -1 \\ 0 \ , \left|x^c\right| < 1 \\ \infty \ , \ x^c > 1 \end{cases}$$

the element A_5 = $Á_5$-1, where Á is the value that would be used with the original Chua-Yang model.

4. Network boundary conditions for state and input can be set to any analog value and can be considered as a part of the template.

5. According to previous characteristics, the CNNUC3 has 22 parameters that we have to define: 9 for each template, 2 for offset and 2 for boundary conditions.

6. The CNNUC3 can accept up to 32 sets of parameters that can be considered as 32 different templates, which should be manipulated with at most 64 digital instructions.

7. The CNNUC3 templates size is 3×3, which represents the kernel dimension for convolution operations.

8. It must be considered that coefficient values range from –127 to 127 (7 bits plus sign). When using the chip, maximum accuracy and speed will be obtained by scaling the coefficients so that the maximum absolute value is 127.

9. Besides the previous observation, considering that the operational voltage range for the CNNUC3 is [0 - 3.3] V, in reality a gray image with 256 levels is translated and scaled to this range where the zero point is at 1.65 V.

10. The ARAM will be used as a cache memory where the acquired image, the results and transitions produce by the CNNUC3 can be stored, previous to be downloaded to the FIPSOC where the decisions will be taken. Note that the ARAM can hold a set of four 64×64 images.

11. The FIPSOC has configurable analog blocks and programmable digital logic, which decrease considerably the number of integrated circuits. As consequence it permits to build a compact CNN-C with an expected lower power consumption

12. The FIPSOC can download the results and communicate to a PC by a serial port.

The CNN Computer capabilities will permit to perform almost any image processing task in real time. The principal advantage of this system is the ability to process analog signals without additional conversions to digital data; such ability reduces greatly processing time. Once all programmed tasks are performed, the conversion is done in order to transmit the results to an ordinary computer where they will be studied.

5. VISUAL INSPECTION WITH THE CNN-C

Since the CNN introduction, many applications have been proposed and tested. Image processing is an immediate application for a CNN. The principal applications for images are directed but not limited to:

1. Extraction of characteristics.

2. Noise removal.

3. Connected component detection.

4. Hole filling.

5. Shadow detection.

6. Image thinning and ticking.
7. Small object isolating.
8. Half toning.
9. Information compression.
10. Character recognition.
11. Filtering.
12. Pattern recognition.

Depending the kind of defects to detect or the type of material to analyze, many of the mentioned applications can be employed in the visual inspection task. An example of defects that we can find when performing a visual inspection and some of the expected results are presented in Figure 4. These results can be considered preliminary because it is necessary to perform a very simple process, which validate, evaluate or register the presented information.

The CNN equation has interesting properties, which permits to develop the mentioned tasks and some others, which remain unknown or have not been considered. All of that it is just because we have an unlimited universe when we are building the templates, which influence directly in the results. Templates construction has been considered for researchers in this area and it is a topic of study, for example, we can mention that genetic algorithms are employed to determine the templates that best fit for a specific application[6, 7.]

Works related to CNN applications have proved the effectiveness of this kind of circuit for image processing. Then, we can say that an effective visual inspection task can be performed with the CNN Computer overcoming the inconveniences relative to time processing. Note that it is necessary to define the objectives of the visual inspection task in order to design the CNN templates and program the system correctly.

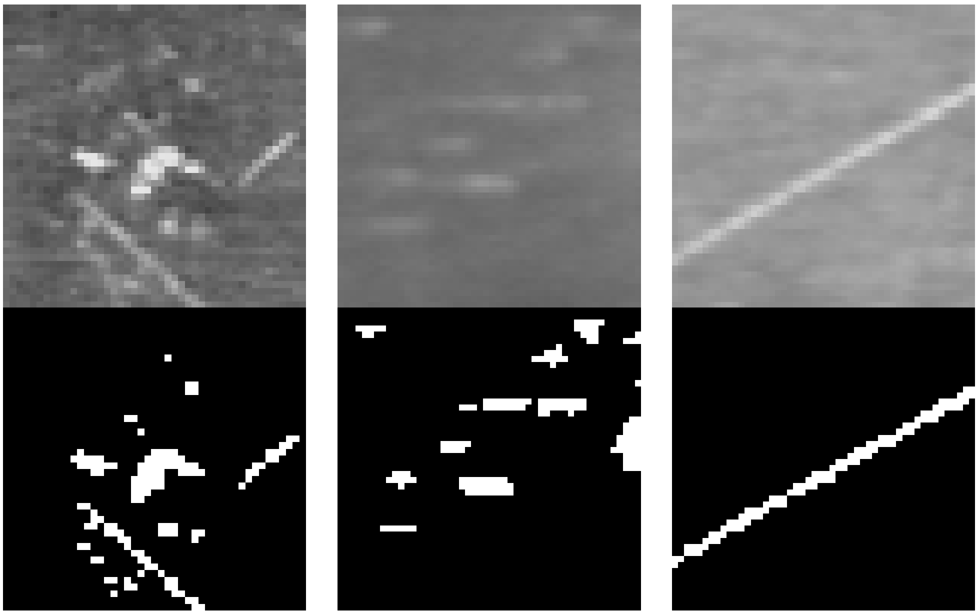

Figure 4. Some possible defects and expected results when performing a visual inspection process.

6. CONCLUSIONS AND PERSPECTIVES

We have presented the design of a CNN Computer be employed in industrial visual inspection as a non-destructive tool, which satisfy the industrial necessities and the consumer demands. This system can produce real-time results and it can perform a variety of image processing tasks involved in visual inspection adequately modulating its parameters, mainly, the CNN templates ones.

In the other hand, time-frequency and time-scale analysis is still an interesting and useful area, where the proposed system can be exploited, for example, the implementation of the pyramidal wavelet transform[8]. This has been performed here with the Haar wavelet where four filtering templates were constructed. It is known that Harr wavelet is not the best one but it is just an initial study that shows the possibilities of the CNN based systems. The singularity detection also has been studied with Gaussian kernels obtaining satisfactory results [8].

REFERENCES

1. L. O. Chua and L. Yang. "Cellular Neural Networks: Theory". *IEEE Trans. on Circuits and Systems*. Vol. **35**, No. 10. pp. 1257-1272. October 1988.
2. G. Liñan, R. Dominguez-Castro, S. Espejo and A. Rodriguez-Vazquez. "CNNUC3 User’s Guide". Technical Report, Instituto de Microelectronica de Sevilla. 1999.
3. T. Roca, S. Espejo, R. Dominguez-Castro and A. Rodriguez-Vazquez. "IMAGAV-1 User’s Guide". Technical Report, Instituto de Microelectronica de Sevilla. 1998.
4. R. Carmona and T. Kozek. “The AM8192C Random Access Analog Memory Chip”. Technical Report, Nonlinear Electronics Lab, U. of California at Berkeley, 1997.
5. J. Faura, P. Naish, P. Paddan, B. Krah, P. Van Doung, J. M. Moreno, A. Torralba, J. Launa and J. M. Insenser. “FIPSOC: A New Concept of Mixed Signal Integration”, Technical Report, SIDSA et al.
6. V. M. Preciado, D. Guinea, J. Vicente. M. C. Garcia-Alegre and A. Ribeiro. “Automatic CNN Multi-template Tree Generation”. *Proc. of CNNA 2000*, Catania, Italy, 2000.
7. V. M. Preciado, D. Guinea, J. Vicente. M. C. Garcia-Alegre and A. Ribeiro. “CNN’s design by GA’s”. *Proc. of ECCOMAS 2000*, September 11-14, Barcelona, Spain, 2000.
8. R. Montufar-Chaveznava, D. Guinea, M. C. Garcia-Alegre and Victor M. Preciado, “The 2-D Wavelet Transform in Cellular Neural Networks”, *Proc. of the IASTED International Conference Signal Processing and Communications*, September 19-22, 2000, Marbella, Spain. Editor: M. H. Hamza, pp. 372-376, 2000.