Performance of artificial neural networks and genetical evolved artificial neural networks unfolding techniques

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With the Bonner spheres spectrometer neutron spectrum is obtained through an unfolding procedure. Monte Carlo methods, Regularization, Parametrization, Least-squares, and Maximum Entropy are some of the techniques utilized for unfolding. In the last decade methods based on Artificial Intelligence Technology have been used. Approaches based on Genetic Algorithms and Artificial Neural Networks have been developed in order to overcome the drawbacks of previous techniques. Nevertheless the advantages of Artificial Neural Networks still it has some drawbacks mainly in the design process of the network, vg the optimum selection of the architectural and learning ANN parameters. In recent years the use of hybrid technologies, combining Artificial Neural Networks and Genetic Algorithms, has been utilized to. In this work, several ANN topologies were trained and tested using Artificial Neural Networks and Genetically Evolved Artificial Neural Networks in the aim to unfold neutron spectra using the count rates of a Bonner sphere spectrometer. Here, a comparative study of both procedures has been carried out.

Keywords: Neutron spectrometry; neural networks; evolutive algorithms.

Con el espectrómetro de esferas Bonner se puede obtener el espectro a traves de un procedimiento de reconstrucción. Los métodos Montecarlo, de Regularizacién, de parametrización, de mínimos cuadrados, de la máxima entropía son algunas de las técnicas utilizadas para la reconstrucción. En la última década, se han utilizado los métodos basados en la tecnología de Inteligencia Artificial. Se han desarrollado métodos basados en Algoritmos Genéticos y Redes Neuronales Artificiales en un intento de resolver las desventajas de las técnicas mencionadas. Sin embargo, a pesar de la ventajas de las redes neuronales, las mismas presentan algunos inconvenientes principalmente en lo que se refiere al proceso de dieño de de las redes, por ejemplo, la selección óptima de los parámetros de arquitectura y aprendizaje. En años recientes, también se ha utilizado tecnologías híbridas, combinando las redes neuronales y los algoritmos genéticos. En éste trabajo, se diseñaron y entrenaron varias topologéas de redes neuronales y redes neuronales evolucionadas geneticamente con el objetivo de reconstruir espectros de neutrones utilizando las tasas de conteo de un espectrómetro de esferas Bonner. Aquí se realiza un estudio comparativo de ambos procedimientos.

Descriptores: Espectrometría de neutrones; redes neuronales; algoritmos evolutivos.

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1. Introduction

Neutron energy spectra found in workplaces are often complex, the range of neutron energies involved can extend over nine or ten orders of magnitude. To improve the assessment of personal equivalent dose (Hp) and ambient dose equivalent (H * (10)) in workplace, requires the proper characterization of neutron spectra [1]. The monitoring of occupational radiation exposure in neutron fields is mainly done with multi-element systems where each element has a particular response to neutrons. With the neutron spectrum information and neutron fluence-to-dose conversion coefficients, different dose quantities, like Hp or H * (10), can be estimated.

With the count rates taken with the Bonner Spheres Spectrometer (BSS), the neutron spectrum can be unfolded. In BSS, each detector is characterized by a response function, the whole set is the response matrix. The relationship among neutron spectrum, count rates and response matrix is described by the integral-differential equation of Fredholm of first type. Due to the number of detectors is smaller than the number of energy groups used to describe the spectrum, resulting problem is ill-conditioned therefore, unfolding procedures should be applied [1]. In previous works, have been reported neutron spectrometry and dosimetry results, by using the Artificial Intelligence (AI) technology as alternative solution. The Artificial Neural networks (ANN) [2] have re-

ceived the higher attention among researchers [1], however, the use of this technology is not free of problems [3].

ANN technology is a useful alternative to solve the neutron spectrometry problem, however, several drawbacks must be solved in order to simplify the use of these procedures. Many of the previous studies in neutron spectrometry and dosimetry by using the ANN approach, have found serious drawbacks in the ANN design process itself, mainly in the proper determination of the structural and learning parameters of the networks being designed. These parameters are significant contributing factors to the ANN performance; however, the optimal selection follows in practical use no rules because they are generally heuristically chosen by using the trial and error technique, which produces networks with poor performance and low generalization capacity. For the anterior, the nuclear research community needs approaches that implement ANN models faster than what is currently available. In consequence, more research has been suggested in order to overcome these drawbacks.

Recently, the use of ANN technology has been applied with success in the neutron spectrometry and dosimetry problems, using a novel approach known as Robust Design of Artificial Neural Networks (RDANN) methodology in the design process of the networks [3]. Another promising technique for ANN design, is to introduce the capacity of adaptation to the net by using Evolutionary Algorithms (EA) [4], which can be used to adapt the connections among the synaptic weights, the design of the architecture, the adaptation of the learning rule, etc. The use of a hybrid technology based in the RDANN methodology combined with EA for the modelling of ANN applied in the neutron spectrometry and dosimetry problems could be a very convenient alternative technique. In this work, several ANN topologies were trained and tested using two ANN design approaches, to and the optimum parameters of ANN. The networks were designed in the aim to unfold neutron spectra using the count rates of CIEMAT BSS, Spain. Here, a comparative study of both procedures has been carried out.

2. Materials and methods

ANN and EA are two relatively young research areas that were subject to a steadily growing interest during the past years. Until today, many researchers still prefer use the gradient search method Back Propagation (BP) in training ANN [2]. However, this technique is a local search method and when applied to complex nonlinear optimization problems, can sometimes result in inconsistent and unpredictable performances. One of the main hindrances is due to the fact that searching of optimal weights is strongly dependent on initial weights and if they are located near local minima, the algorithm would be trapped; if the initial guess of the ANN is near local maxima, it will climb the gradient and get stuck. The structure of a neural network is a significant contributing factor to its performance and the structure is generally heuristically chosen. Several different attempts have been proposed by various researchers to alleviate the training problems. The use of EA as search technique has allowed different properties of ANN to be evolved.

In this work, the performance of neural nets, designed for the BSS of CIEMAT, with two desing methodologies is compared. The traditional nets (ANN) were designed by means of the RDANN methodology and the Evolutive ANN (EANN) [4], were designed by using the computer program known as NeuroGenetic Optimizer (NGO) [5]. To use the knowledge stored at the networks designed with both metodologies, friendly computer programs whit graphical interfaces were designed and builded respectively. A modified version of the NSDann unfolding code was used for the traditional ANN [6], and the unfolding code called "Neutron Spectrometry and Dosimetry based on Evolutive Artificial Neural networks" (NSDEann) was designed for EANN.

In both cases, the first layer (input) corresponds to the 12 Bonner spheres of the CIEMAT's BSS, the hidden layers and neurons by layer should be determined and the third layer (output) has 85 neurons. The first 72 outputs correspond to the neutron spectra and the remaining 13 are equivalent doses. In both methodologies training was carried using 201 spectra, and 50 spectra were used for testing the learning of the nets.

Utilizing the RDANN methodology, additional parameters have to be determined: momentum, learning rate, training algorithm and mean square error (MSE). The EANN technology, although does not requires on the part of the user ANN parameters to be determined, it requires the determination of parameters regarded with the GA used to and the architecture of the net.

This is a very difficult problem, which is similar to that found in ANN design and, at present, this represents a serious drawback of the EANN approach, because the parameter selection is done through the trial and error technique. More research is needed in this sense. At present, work is being carried out. The neutron spectra unfolded and its corresponding 13 equivalent doses were computed with the modified NSDann and NSDEann unfolding codes, for a ^{239}PuBe neutron source measured at 80 cm distance, at "Departamento de Ingeniería Nuclear" (DIN) of "Universidad Politécnica de Madrid" (UPM).

3. Results and discussion

By means of the RDANN methodology, 36 traditional ANN topologies were designed and trained, each in a time of 107 seconds average. The optimum network topology is: 12 neurons in the input layer, 16 nerons in a hidden layer and 85 in the output layer. The neural nets were trained until MSE was reduced to 10^{-4}. Additional parameters are: momentum: 0.001, learning rate: 0.1, training algorithm: trainscg. After the training and testing stages, the knowledge stored at synaptic weights was extracted and a modified version of the NSDann unfolding code was designed. Figure 1, shows the

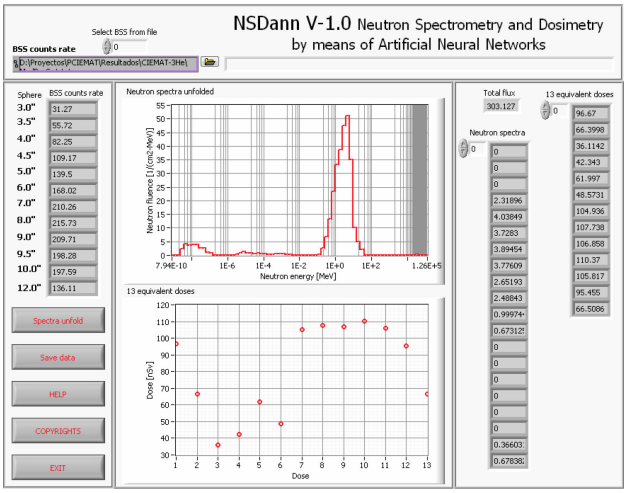

FIGURE 1. Neutron spectra unfolded and equivalent doses calculated with NSDann.

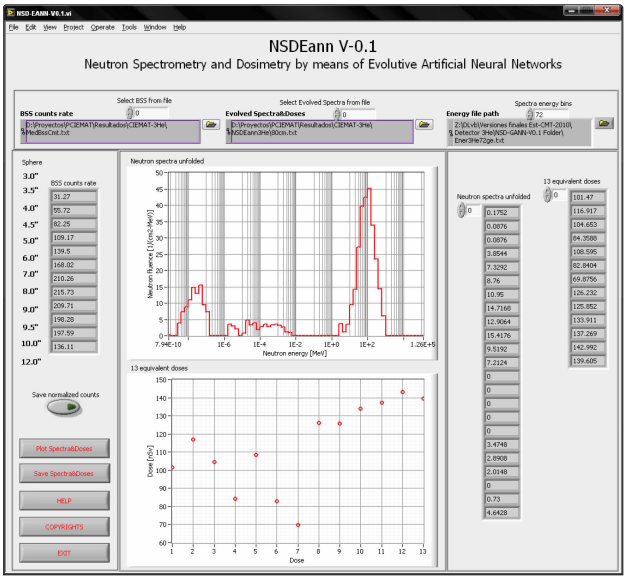

FIGURE 2. Neutron spectra unfolded with NSDEann.

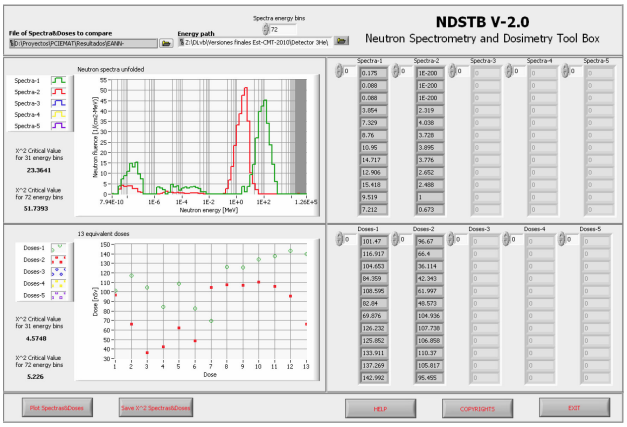

FIGURE 3. Neutron spectra unfolded with NSDann - NSDEann.

neutron spectra unfolded and its 13 equivalent doses calculated by means of the modified NSDann code.

By using the EANN methodology, 600 EANN were designed and trained in a time of 04:44:09. The minimum network training passes for each network were 420, the cutoff for network training passes was 450, and the limit on hidden neurons was 8. The optimum network topology is: a Fast-Back Propagation neural network with 12 inputs, 6 logistic neurons in a hidden layer and 85 neurons in the output layer, with an accuracy on training set= 99.50% according NGO. The parameters used for the GA, selected using the trial and error technique, are: generations run: 10, population Size: 60, selection was performed by the top 50% surviving, re?lling of the population was done by cloning the survivors, mating was performed by using the TailSwap technique, mutations were performed using Random Exchange technique at a rate of 25%.

After the training and testing stages, it was not possible to extract the knowledge stored at synaptic weights of the network designed with NGO. For this reason, the NSDEann unfolding code was designed to read and graph the spectrometric and dosimetric information produced by means of the EANN trained with NGO. Figure 2, shows the neutron spectra unfolded and its 13 equivalent doses calculated by means of the modified NSDann.

In order to compare the results obtained with the NSDann and NSDEann unfolding codes, the computer tool known as "Neutron spectrometry and dosimetry Tool Box" (NSDTB) was used [7]. Figure 3, shows the performance of the neutron spectra unfolded with the EANN approach (green line) and the spectra unfolded with the RDANN methodology (red line) and its corresponding 13 equivalent doses. As can be seen, the spectra and doses present diferencies, this is due mainly to the trial and error approach used to select the GA parameter in the EANN approach, which is a serious drawback of this method. More research is needed in this sense. At present work is being developed to overcome these drawbacks.

From Fig. 3, can be observed that the neutron spectra unfolded and equivalent doses calculated with both, traditional ANN and EANN, are very similar, however, the EANN unfold the spectra in different energy bins, this makes that the $\chi 2$ test fails. A deeper analysys should be needed in order to observe closer what could be happening.

4. Conclusions

The use of ANN technology is a useful alternative to solve the neutron spectrometry and dosimetry problems; however, to obtain the best results, some drawbacks must be solved in the ANN design process, such as the optimum ANN topology selection.

In this work, the ANN optimization methodology known as RDANN, was used to design an ANN capable to solve the neutron spectrometry and dosimetry problems for the

CIEMAT BSS system. The neural net was trained and tested using a large set of neutron spectra compiled by the IAEA.

The success of ANN technology in neutron spectrometry and dosimetry, using only the Bonner spectrometer count rates as input in the trained network will overcome some of the problems associated with the solution of such ill-conditioned problem. The results here reported demonstrate that the use of this technology has become in a useful tool.

Until now RDANN methodology seems to be mo reliabe in the neutron spectra unfoloding problem, because more research has been carried out in this sense and consecuently more information is available. The main drawback of EANN is the trial and error technique used to determine the optimum values of the GA used to build the network. The combination of RDANN whit GA could improve widely the results obtained with both methodologies.

More research is needed and at present, work is being carried out.

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