STUDY OF ACCURACY OF THE PHYSICAL PARAMETER EVALUATION BY USING THE NEURAL NETWORKS APPROACH

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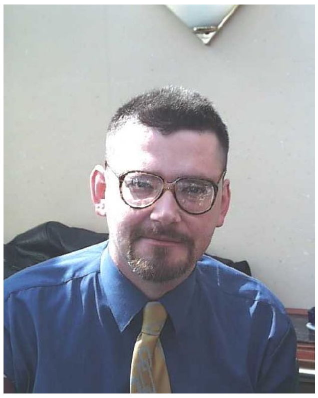
Abstract:

Nuclear Safeguards includes tools and concepts for quantification, detection and monitoring of nuclear materials. Gamma multiplicity theory has been developed recently in addition to neutron multiplicity theory for assay of nuclear materials or nuclear waste. The total number of measurable multiplicities exceeds the number of unknowns parameters, such as the sample fission rate, the leakage multiplication and the α ratio and γ ratio. Artificial neural networks (ANN) has been used to evaluate the unknown parameters of nuclear material, since an analytical inversion of the highly non-linear system of over-determined equations is not possible. The parameters have been unfolded with high accuracy, especially the most important parameter such as sample fission rate which is proportional to mass of fissile sample. Simulations are executed on few different hardware platforms. Parameters used in physics problem and number of epochs in learning of the network are variated and used in the comparative perfomans study of different hardware platforms.

Keywords: **neutron and gamma multiplicities, neural networks, core2 duo, core2 quadd.**

Presenting Author's biography



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1. Introduction

Quantification, detection and monitoring of nuclear materials are of high priority in the field of nuclear nonproliferation and homeland security. Nuclear materials themselves can range from hospital radioisotopes to weapons grade materials. Neutron multiplicity theory and neutron counting have been used for assay of nuclear materials for a long time. Characterization of fissile material is basically relied on the analytical solution of a system equations on the first three moments of the neutron multiplicity distributions. The correct derivation of the neutron multiplicities rates from analytical expressions for the neutron factorial moments is recently published in Ref. [1]. The similar theory of gamma rays on gamma ray multiplicity counting has been developed recently. The combined use of both the individual neutron and gamma multiplicities, as well as their joint multiplicities and the corresponding detection rates has been lately suggested for determining sample parameters [2,3]. Advantages of the use of organic scintillation detectors in the area of nuclear safeguard for measurements in mixed neutron/gamma-ray fields because of its excellent pulse shape discrimination characteristics have been emphasized in recent publications [4,5].

The measured multiplicity rates contain useful information on the sample parameters unfolding. Due to complexity of the expressions for the gamma multiplicities as well as the complexity of the joint neutron and gamma multiplicities it was not possible to perform analytical inversion of the multiplicity rate expressions, which was possible for the neutron expressions. Therefore, the artificial neural network (ANN) technique has been applied to unfold the sample parameters from the measured multiplicity rates [6,7].

The use of 3 neutron, 3 gamma and 3 mixed multiplicity rates in the sample unfolding represents over-determined system with 9 measurable quantities exceeding the number of unknowns, i.e. sample parameters. It was demonstrated that the sample parameters such as fission rate, the probability of induced fission p, the alpha ratio expressing the rate of (α,n) reactions compared to the spontaneous fissions, the gamma ratio expressing the ratio of the single gamma ray source strength and the neutron source strength and the gamma detection efficiency can be unfolded with the small relative errors from 9 input multiplicity rates (3 neutron, 3 gamma and 3 mixed multiplicity rates) [8]. We have used the backpropagation neural network with two hidden layers with 25 and 15 nodes, respectively and tansig activation functions in both layers. The output layer with linear activation function contains 5 nodes for 5 output parameters. The training data were generated for parameters corresponding to samples ranging from a few tens of grams to the kilogram range. The Levenberg-Marquardt algorithm has been used for learning the network.

The results obtained has shown that the physical parameter evaluation can be performed with high accuracy with the various number of epochs in the training procedure. The 3000 epochs has been accepted as the optimal number of epochs regarding the accuracy of the parameter evaluation and time comsuption.

2. The relative errors of the parameters evaluated by the ANN

This study includes investigation of the relative errors of the evaluated parameters of fissile sample, such as the sample fission rate, the leakage multiplication, the alpha ratio, gamma ratio, as well as gamma efficiency depending on the number of epochs in the training process. Analysis of the results obtained for the fission rate as the most important parameter of the fissile sample has shown that the relative errors are decreasing with increasing the epochs number up to 4000 epochs. However, for 5000 epochs and more, due to high non-linearity of the problem itself, the relative errors are increasing. Taking into account the tradeoff between the accuracy and time consumption, we have chosen 3000 epochs as the optimal number for evaluation of the fission rate. The results of investigation of the relative errors depending of the number of epochs for the fission rate are given in Table 1 and are shown in Fig. 1. The results presented in Table 1 and Fig. 1. are related to minimum and maximum values of the relative errors, as well as to mean values and standard deviations.

The relative errors of the alpha parameter which takes into account the rate of (α,n) reactions compared to the spontaneous fissions, has shown the similar behavior as the fission rate depending on the number of epochs. The results obtained are presented in Fig. 2. It can be noticed in Fig. 3-5 the similar dependence of the rest parameters (p parameter, gamma ratio and gamma efficiency) on the epochs number.

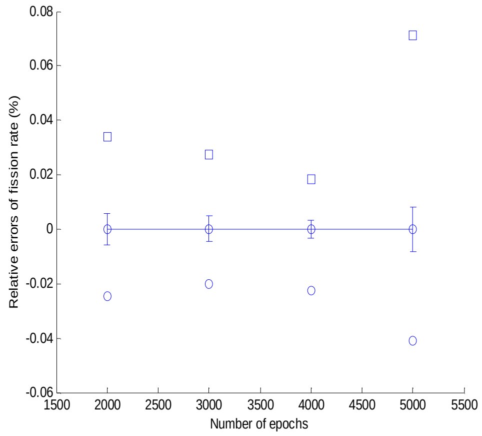

Fig.1 The relative errors of the fission rate depending on the number of epochs.

Table 1. Basic parameters of descriptive statistics for the fission rate depending on the number of epochs.

	Number of epochs			
Relat. errors (%)	2000	3000	4000	5000
Mean	-0.00	0.00	-0.00	-1E-4
Std.dev	.0056	.0047	.0034	.0081
Maxi	0.034	.0275	.0185	0.071
Mini	-.0246	-.0199	-.022	0.071

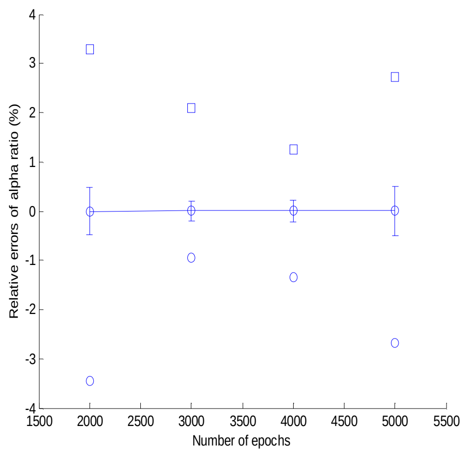

Fig. 2. The relative errors of the alpha ratio depending on the number of epochs.

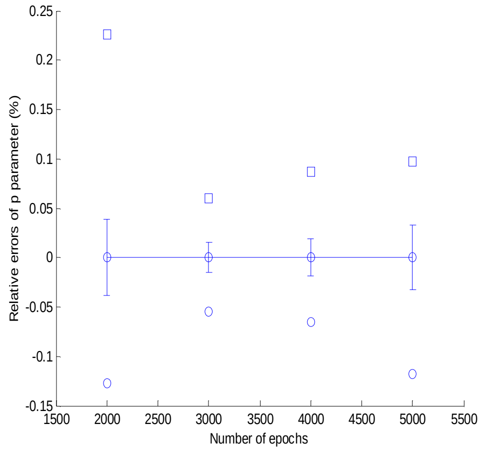

Fig. 3. The relative errors of the p parameter depending on the number of epochs.

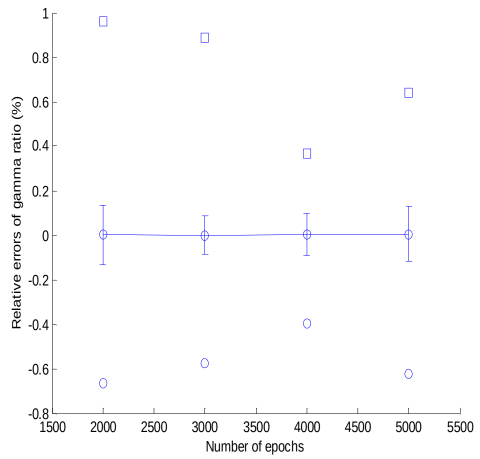

Fig. 4. The relative errors of the gamma ratio depending on the number of epochs.

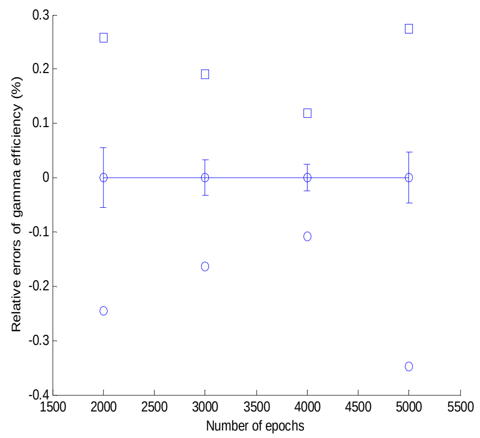

Fig. 5. The relative errors of the gamma efficiency depending on the number of epochs.

3. Comparative perfomans study of different hardware platforms

Accuracy of the physical parameter evaluation has been investigated by simulations in program package MATLAB. Simulations are executed on few different hardware platforms. This physics problem is good benchmark test and therefore it is used for comparative performans study of different hardware configurations. Two configurations are used for testing: core2 duo (3.0 Ghz)/4Gb RAM (Intel E8400 Processor) and core2 quadd (2.83 Ghz)/8Gb RAM (Intel Q9550 Processor). Number of epochs in learning of the network are variated and used in study. Results of the comparative study are written in Table 2.

Table 2. Comparative Study between different hardware configuration

	Number of epochs			
	2000	3000	4000	5000
E8400	4357 [s]	6539 [s]	8714 [s]	10878 [s]
Q9550	3591 [s]	5399 [s]	7175 [s]	8259 [s]

This study is not tested on more complex and high performance graphics card (GPU with CUDA capability), because this hardware is not available for authors. It should be useful to repeat same simulations on GPGPU systems and to add such results to comparative table.

4. Conclusion

The revival of nuclear power requires advanced nuclear materials control and accountability in order to ensure safety. Quantification of Pu-239 and other fissile isotopes are of high interest in the field of nuclear nonproliferation and homeland security. Recently developed neutron and gamma multiplicity theory has been applied to evaluate unknowns parameters of the fissile sample, such as the sample fission rate, the leakage multiplication and the α ratio and γ ratio. The ANN approach could handle both the non-linearity and the redundance in the measured quantities. The parameters have been unfolded with high accuracy by using the backpropagation network constructed with two hidden tansig layers and a linear output layer. Time comsuption of the parameters evaluation has been investigated on two different hardware platforms depending on the number of epochs. It was demonstrated that the 3000 epochs represents the optimal number of epochs regarding the accuracy of the parameter evaluation and time comsuption.

Aknowledgement

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