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Application of Neural Network for the gamma-hadron discrimination

G.M. Maneva, P.P. Temnikov

Institute for Nuclear Research and Nuclear Energy, 72, Tzarigradsko chaussee Blvd., 1784 Sofia, Bulgaria

J. Procureur

Centre d'Etudes Nucleaires de Bordeaux-Gradignan, 33175 Gradignan-Cedex, France

Abstract.
Artificial Neural Network (ANN) method is applied for the analysis of raw data from the gamma ray CELESTE experiment. Our preliminary results show that, in the energy range 30-300 GeV, a good discrimination between showers generated by primary photons or hadrons could be obtained.

Key words: Gamma astronomy on the ground

1. Introduction

In a paper of the present Symposium, D. Smith, spokesman of the new CELESTE experiment in gamma astronomy, discusses the fundamental scientific interest to observe cosmic photons in the energy range [30-200] GeV, (see also M. de Naurois, 1999) and describes the experimental set-up. So, in this work, we will not give details of CELESTE but we would like only to remind that this kind of observation implies some specific new difficulties because of the very weak flux of the Cerenkov light produced in showers generated by cosmic primaries with low energies. As an example, in showers generated by primary gamma quanta with energy around 30 GeV, in average only three photo-electrons will be detected on each of the forty heliostats in the CELESTE array, (each of them: 54 m^2). One central problem is, knowing the amplitudes and arrival time of photo-electrons on each heliostat, to be able to determine the nature of the primary particle inducing the observed showers. To solve this basic problem, the usual way is to select showers step by step using different selection cuts. As an example, for the CELESTE array, such cuts are based on the signal amplitudes, correlations between heliostats or the homogeneity of the Cerenkov front wave. It was interesting, for the photon-hadron discrimination, to use a completely independent way which can be obtained using ANN methods. Such analysis of the Cerenkov light in atmospheric showers has already been made in past for energies around the TeV, (G. Sembroski and M.P. Kertzman, 1991, F. Halzen et al., 1991, C.L. Bhat at al. 1995, P.T. Reynolds et al., 1997). It has been concluded that for energies larger than some hundred GeV, results obtained using ANN were at least as accurate as χ^2 fitting techniques. In our previous publication (Dumora D. et al.) we have demonstrated that ANN method could be used successfully for analysis of Cerenkov light showers detected by the CELESTE experiment. In this article we use more realistic and higher statistics Monte Carlo simulated data and apply the trained network for separation of gamma and proton induced showers in the real data sets.

2. Data structure and the ANN architecture

Data taking in the CELESTE experiment was organised in pairs of ON-OFF observations. The ON observation tracked the source during about 20 minutes and corresponding OFF data sets were taken following the same trajectory immediately after or before the ON one. We used in our analysis the package JETNET (C. Peterson and T. Rögnvaldsson, 1993), widely used in high energy physics. The architecture of the networks is dictated by the experimental information: 40 pairs of amplitudes and arrival times for each heliostat. We have chosen an input layer with 80 nodes connected with 40 nodes of the first hidden layer. Each of these 40 nodes were connected only with one pair of the input layer. The 10 nodes of the second hidden layer were connected with all nodes of the first one. And finally, output node was connected with all nodes of the second hidden layer. The target values of the output was set to -1 for gamma shower and +1 for proton one. The network architecture is shown in figure 1.

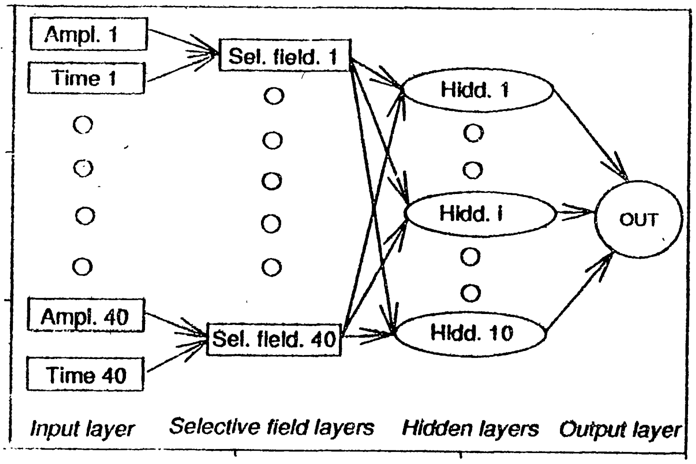

Figure 1.

The activation function was chosen as tanh(x). The inputs values for active heliostats were normalised to intervals from 0 to 1 separately for amplitudes and arrival times. If the input values for given heliostat were not measured, their value were set to 0. We used the feed-forward ANN with back-propagation procedure of the error function minimisation. In order to avoid getting into a local minima a Gaussian noise term was added to the standard procedure of weights updating,(so called Langevin uptading mode).

3. Training and testing steps

Training of a network means adjusting weights to minimise the so called error function $E = \sum(xout_i(weights, inputs) - target_i)^2$ where the sum is over all events (patterns). In our case, target is respectively -1 and 1 for primary photons and hadrons. The minimisation is performed in so called "on line mode", after any 10 teaching showers have been presented. During supervised training of the network it is very important to avoid the over-learning (too detailed description of training patterns) and at the same time to get good generalisation (capability to classify patterns from unseen data set). Normally data is divided into 2 data sets. The first one is called training set and is used for minimisation purpose, and second one, called testing set is used to check the quality of minimisation. Ingredients for the neural net working are showers generated by primary photons and hadrons. For the training, testing procedures, the gamma showers have been simulated using the CORSIKA code, (D. Heck et al., 1998). These simulations have been performed describing the shower development by full Monte Carlo methods and taking into account the detector responses and night-sky light background. Gamma showers have been simulated for primaries in the energy range (30-300) GeV following the energy spectrum index -2. The simulation of proton showers must be done in much wider energy interval and is very time-consuming due to the rejection of simulated shower by the trigger. We decided to use the OFF data samples as a source of patterns (events) of proton induced showers obtained by CELESTE close to the zenith of the Crab. We have to notice that these showers are not generated by only hadrons. Some of them are produced by primary electrons and could be interpreted as gamma-like showers. Others are because of diffuse primary photons which could be neglected. For training and testing, we used a mixed composition taking into account 50% of gamma showers and 50% of hadron showers. The training procedure was performed with 9100 Monte Carlo simulated gamma-induced showers and the same quantity of real OFF events. The testing was done over 1500 showers from any of these types. Typical behaviour of the error function with increasing number of iteration is shown in figure 2, (one epoch is called a full cycle of minimasing iterations over the whole set of training events). The lower curve is for training set and upper for testing one. It is seen that the error for testing set after certain number of epochs reaches minimum point, while for training set it continues to decrease. It means that ANN starts to describe some specific features of training patterns. We have to stop the learning somewhere in the region of broad minimum of testing curve. To find exact point we used several additional characteristics: efficiency of gamma showers identification, probability to misidentify proton shower and purity of selected gamma showers sample. We applied this procedure for every OFF run separately.

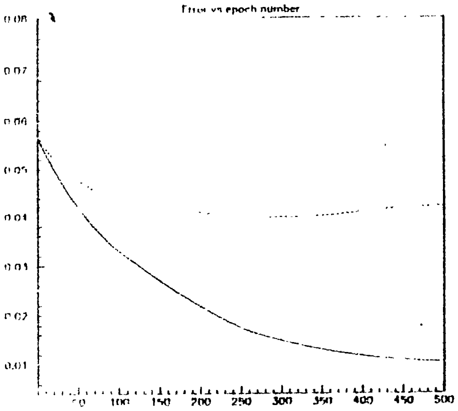

Figure 2.

4. Results

After training the ANN described in the previous section, we analysed five pairs of data sets (ON,OFF) detected by the CELESTE experiment. Each pair (ON,OFF) consisting of about 40000 observed showers.

As an example, figure 3 shows the quality of the obtained photon-hadron discrimination analysing one experimental ON data set. On this figure, to highlight the relative size between the gamma and hadron peaks, log scale has been used.

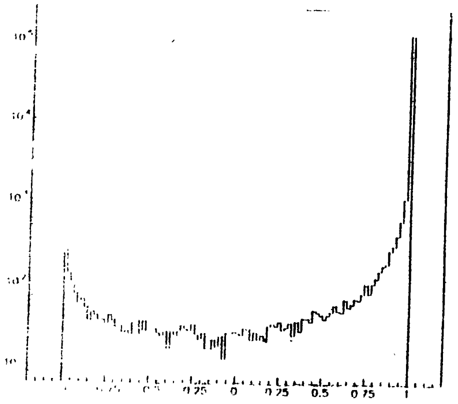

Figure 3.

In figure 4 are shown the results of ANN processing of 127677 "ON" and 126899 corresponding to them "OFF" Cerenkov showers. Here we have presented only the part of the histograms connected with the gamma-like selective capability of ANN. In order to observe some difference between the ON and OFF runs, we have presented here the subtraction of ON and OFF histograms of the ANN output value "xout", (with corresponding statistic errors). As it can be seen it is averaged around 0 except to values close to -1 showing some excess of gamma showers in the ON data. In other words, as expected, the ON data seem richer in gamma-like showers than the corresponding OFF measurement.

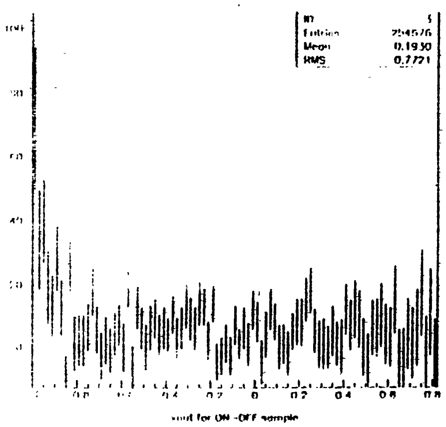

Figure 4.

5. Conclusion

The aim of the present work is to evaluate the feasibility of employing Artificial Neural Networks, (ANN), to solve the problem of the photon-hadron discrimination in showers detected by the new CELESTE experiment. In this purpose, we used gamma showers simulated by pure Monte-Carlo processes and the experimental OFF data as hadron showers. After training and testing steps the experimental ON-OFF data has been analysed. Our conclusion is that ANN seems to give useful possibilities for the gamma-hadron discrimination. It is important to point out that the present results are very preliminary and have not to be taken as definitive because many tests have to be done to confirm our conclusion. For example, we have to check the angular distribution of gamma-like showers which should have maximum at zero angle. In an other way, for the gamma-hadron discrimination, the CELESTE team is using different cuts, (M. de Naurois, 1999), and it is a basic problem to verify if there is some convergence between the gamma showers selected using the two independent way, experimental cuts or ANN. All these checks are in progress for the present time.

4. Acknowledgments

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