Multivariate Methods of Data Analysis in Cosmic Ray Astrophysics

A.A. Chilingarian [a], A.A. Vardanyan[a]

[a]Cosmic Ray Division, Yerevan Physics Institute,
2 Alikhanyan Brothers street, 375036 Yerevan, Armenia

This report will present coherent system of multivariate statistical methods dealing with analysis of data of stochastic nature. All stages of analysis, from preprocessing to sophisticated physical inference on the theoretical models under consideration are presented with numerous examples of applications.

1. Introduction

Each time new type of detectors started to detect Universe they revealed details of a cosmos that don't show up through the eyepiece of an optical telescope. Indeed, every part of the electromagnetic spectrum surprised astronomers in one way or another. And only simultaneous detection of all 25 magnitudes of energy by different kinds of detectors, starting from radio telescopes to giant arrays measuring ultrahigh energy cosmic rays, will allow understanding physics of such exotic objects like black holes, and neutron stars, and such energetic processes like supernova explosions and gamma ray bursts.

Though each experimental device created to detect new type of radiation is a technical breakthrough, we need also intellectual breakthrough to understand and handle abundant multidimensional information available from numerous sensors measuring various types of particles.

One of the most important problems in physical inference from multivariate measurements is development of the reliable statistical procedures dealing with information from modern multipurpose experimental installations.

2. Analysis and Nonparametric Inference (ANI)

Nowadays, when multidimensionality of physical phenomena is well recognized and experimental techniques reach excellence to measure simultaneously many parameters with high precision, the necessity of adequate multivariate analysis methods is apparent.

The most general framework in which to formulate solutions to physical inference problems in Cosmic Ray (CR) Astrophysics experiments is a statistical one, which recognizes the probabilistic nature both of the physical processes of cosmic radiation propagation, and of the form in which the data analysis results should be expressed. To make the conclusions about investigated physical phenomenon more reliable and significant we have developed a unified theory of statistical inference, based on nonparametric models, in which various nonparametric approaches and Neural Networks are implemented and compared. In this context it is necessary to mention that we consider the Neural information technology not as a "black box", but as an extension of conventional nonparametric technique of statistical inference. The **A**nalysis and **N**onparametric **I**nference *(ANI)* program package [1] is the software realization of our concept and appropriate tool for the physical inference in High Energy Cosmic Ray Astrophysics experiments. During last 10 years ANI package was updated and intensively used for comparisons of different nonparametric techniques and for data analysis of world biggest experiments, like PAMIR emulsion chamber collaboration, Wipple air Cherenkov telescope, KASCADE, and ANI surface installations for detecting the Extensive Air Showers (EAS).

Due to very limited volume of this publication we are giving references to the original works where ANI package was used for solving physical inference problems in multidimensional noisy environments:

- event-by-event analysis of the X-ray experiment data. Determination of the upper boundary of the iron nuclei abundance in PCR flux, based on the individual event treatment of gamma-hadron families data base. [2,3]

- event-by-event analysis of the EAS. Estimation of the primary type and primary energy for each individual shower. [4–7]

- selection of the pure beams of the cosmic ray nucleus, by EAS data treatment. Tuning of the strong interaction phenomenological parameters from the pool of alternative models realizations. [8]

- multivariate analysis of the Cherenkov images of air showers. [9,10]

- neural analysis of data from imaging air Cherenkov telescope. [11–15]

REFERENCES

1. Chilingarian A.A., Analysis and Nonparametric Inference in High Energy Physics and Astroparticle Physics, 1998, program Package ANI, (Users Manual, unpublished) http://crdlx5.yerphi.am/proj/ani.
2. Chilingarian A.A., Galfayan S.Kh., Dunaevski A.M., Zazyan M.Z. et al, The new method of gamma-families analysis, in Proc. 20 ICRC, vol. 5, p. 312, Moscow, 1987.
3. Chilingarian A.A., Galfayan S.Kh.,Dunaevski A.M., Zazyan M.Z.et al, The upper boundary of of iron nuclei fraction in PCR obtained from PAMIR data, in Proc. 20 ICRC, vol. 1, p. 386, Moscow, 1987.
4. Chilingarian A.A., Zazyan H.Z., A Bootstrap method of Distribution Mixture proportion determination, *Pattern Recognition Letters*, **11**, 781, 1990.
5. Chilingarian A.A., Zazyan H.Z., On the possibility of investigation of the Mass Composition and Energy Spectra of PCR in the energy range $10^{15} - 10^{17}$ eV using EAS data, *IL Nuovo Cimento*, **14C(6)**, 555, 1991.
6. Chilingarian A. A., et al. On the nonparametric classification and regression methods for the multivariate EAS data analysis, *Nuclear Phys. B*, **52A**, 237, 1997.
7. Chilingarian A.A., Roth M., Vardanyan A.A. et al, A nonparametric approach for determination of energy spectrum and mass composition of cosmic rays from EAS observables, *Nuclear Phys. B*, **75A**, 302, 1999.
8. Chilingarian A.A., Zazyan H.Z., Experiments with Particle Bundles in Cosmic Ray Physics. Determination of Strong Interaction Parameters by a Pattern Recognition Method, *J. of Nuclear Phys.*, **54**, 128, 1991, (russian).
9. Aharonyan F.A., Chilingarian A.A., Plyasheshnikov A.K., Konopelko A.K., A Multidimensional analysis of the Cherenkov images of Air Showers induced by Very High Energy gamma-rays and protons, *NIM A* **302**, 522, 1991.
10. Chilingarian A.A., Cawley M.F., Application of Multivariate Analysis to Atmospheric Cherenkov Imaging Data from the Crab Nebula, in *Proc. 22 ICRC*, vol. 1, p. 540, Dublin, 1991.
11. Chilingarian A.A., Neural Net Classification of the gamma and proton images registered with Atmospheric Cherenkov Technique, Random Search Learning in Feed-Forward Networks, in Proc. 22 ICRC, vol. 1, p. 540, Dublin, 1991.
12. Chilingarian A.A., On the methods of the enhancement of the reliability of the signal detection with Cherenkov Atmospheric techniques, in *Izv. AN USSR, Phys.*, vol. 57, p. 186, 1993, (russian).
13. Chilingarian A.A., Cawley M.F., Optimizing the Nonlinear gamma-ray Domain in VHE gamma-ray Astronomy using Neural Network Classifier, in Proc. 24 ICRC, vol. 3, p. 742, Rome, 1994.
14. Chilingarian A.A., Neural classification technique for background rejection in high energy physics experiments, *Neorocomputing*, **6**, 497, 1994.
15. Chilingarian A.A., Detection of weak signals against background using Neural Network Classifiers, *Pattern Recognition Letters*, **16**, 333, 1995.