

Modeling of Soft sensor based on Artificial Neural Network for Galactic Cosmic Rays Application

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Abstract. For successful designing of space radiation Galactic Cosmic Rays (GCRs) model, we develop a soft sensor based on the Artificial Neural Network (ANN) model. At the first step, the soft sensor based ANN was constructed as an alternative to model space radiation environment. The structure of ANN in this model is using Multilayer Perceptron (MLP) and Levenberg Marquardt algorithms with 3 inputs and 2 outputs. In the input variable, we use 12 years data (Corr, Uncorr and Press) of GCR particles obtained from Neutron Monitor of Bartol University (Fort Smith area) and the target output is (Corr and Press) from the same source but for Inuvik area in the Polar Regions. In the validation step, we obtained the Root Mean Square Error (RMSE) value of Corr 3.8670e-004 and Press 1.3414e-004 and Variance Accounted For (VAF) of Corr 99.9839 % and Press 99.9831% during the training section. After all the results obtained, then we applied into a Matlab GUI simulation (soft sensor simulation). This simulation will display the estimation of output value from input (Corr and Press). Testing results showed an error of 0.133% and 0.014% for Corr and Press, respectively.

Keywords: Galactic Cosmic Rays, Matlab GUI, Artificial Neural Network, Soft sensor

1. Introduction

One example of space radiation environment source is Galactic Cosmic Rays (GCRs), which is harmful to satellite component. Radiation was composed by different particles (neutron, protons, electron and heavier charged particle) up to 10^{20} eV. Many researchers studied about radiation of GCRs such as Bourdarie and Xapsos [1] showing that GCRs are radiation with high energy and originated from the outside of solar system, which strongly causes Single Event Effect (SEE) in microelectronics and photonics. GCRs dominated the effect in terms of Linear Energy Transfer (LET) in satellite application, and this energy is non-linear variable. Shalchi *et al.* [2] discussed more about nonlinear parallel and perpendicular diffusion of charged cosmic rays whereas his study emphasizes the GCRs is non-linear variable and a new theory for parallel and perpendicular diffusion of cosmic rays. Suparta and Putro [3] discussed an analysis distribution of GCRs in polar orbit satellite for Geant4 (GEometry ANd Tracking) application with simulating the GCRs particle. Chris H *et al.* [4] also discussed a cosmic ray model to generate the input tables used for the Cosmic Ray Shower Generator (CRY) and his finished made a GCR model with this simulation. However, this simulation has found some problem including estimated output model. According to this problem, we found that Artificial Neural Network (ANN) with Levenberg Marquardt algorithm is proposed to estimate and measured the model output.



In this study, we focused to create a soft sensor based on ANN and estimate the ground based Neutron Monitor from Bartol University (Inuvik area) where the input data is taken from the same source (such as Fort Smith area). Matlab software is employed to create ANN and Graphic Utility Interface (GUI) of the soft GCR sensor.

2. Methodology

2.1. Collecting data

The fluxes of GCRs radiation is divided into space (Primary GCRs) and ground based (Secondary GCRs). Figure 1 shows the spectrum of galactic protons flux at Earth, where E (GeV) flux is not correlated with the solar wind. As shown in the lower energy, GCR area is in the left of graph with cut off (~ 15 GeV at the equator, 0 GeV at the poles) is higher during solar proton minimum and the other side, Earth’s magnetic field acts as a further filter on the low-E flux spectrum.

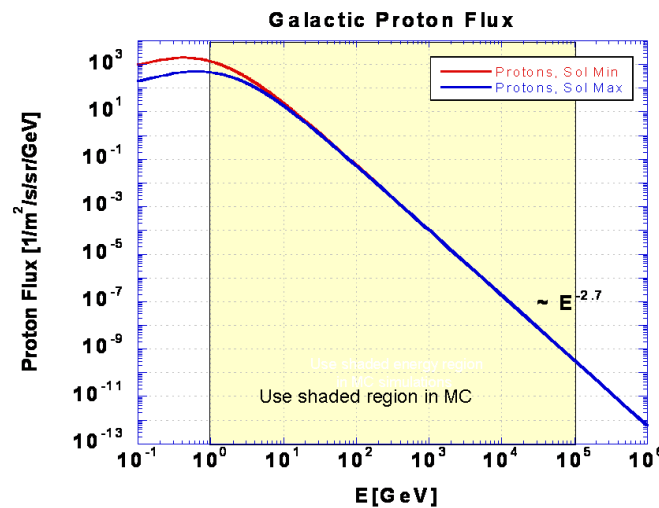


Figure 1. Spectrum of Galactic Protons incident on Earth [6]

In this study, we used 12 years data collected from 1 January 2000 to 31 December 2011. The data was obtained from the ground based neutron monitors at Fort Smith station (60.02°N latitude, 111.93°W and elevation of 206 m) and Inuvik station (Geographic: 68.05°N latitude, 133.70°W and elevation of 21 m) that can be accessed through http://neutronm.bartol.udel.edu/~pyle/bri_table.html. Both ground based Neutron Monitors are located at the North West Territories – Canada. Further, the data was classified of three variables: Corr, Press and Uncorr. Corr data was processed and otherwise is called Uncorr, while Press data is air pressure as shown in Table 1.

Table 1. Ground-base neutron monitors data from Bartol University for two selected stations

Date (Time) yyyy/mm/dd/hh/mm	Fort Smith			Inuvik		
	Corr	Uncorr	Press	Corr	Uncorr	Press
:	:	:	:	:	:	:
2001/01/01/00/00	6802	8422	738.6	6245	6001	763.1
2001/01/01/01/00	6816	8510	737.8	6238	6000	763.0
2001/01/01/02/00	6838	8543	737.7	6249	6017	762.9
:	:	:	:	:	:	:

2.2. Soft sensor based Artificial Neural Network (ANN)

A soft sensor are used to solve a number of different problems such as measuring system back-up, what-if analysis, real-time prediction for plant control, sensor validation and fault diagnosis strategies Luigi [7]. This sensor can process for many variable measurements simultaneously. Figure 2 shows the identification procedure of a soft sensor design, where in the first step is collecting the data from data base until the last step is a data validation.

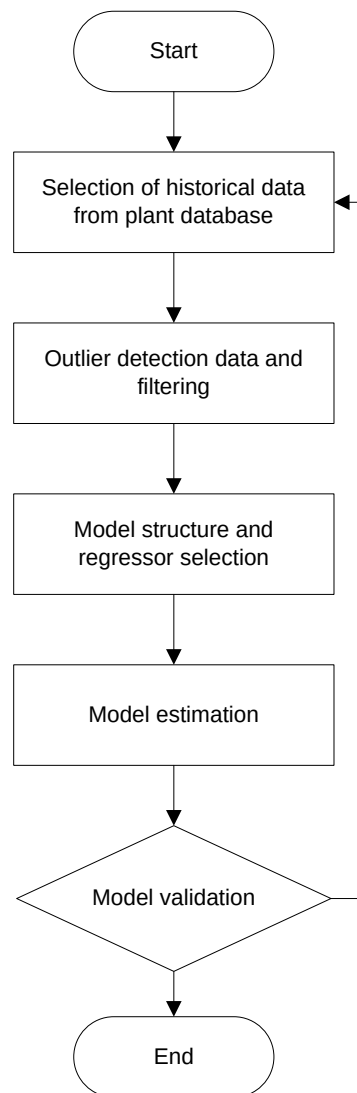


Figure 2. Block scheme of the identification procedure of a soft sensor [7]

There are several methods was used to design soft sensors such as ANN. ANN identification system is an attempt to get a mathematical description (model mathematic) from the dynamical system based on measurement data. It has steps such as experiment, selecting structure model, estimating parameter and model validation. In the experiment section, the variable input and output must be obtained from process description. Below is the common formulas used in the ANN method as described in detail by Laurence [8]. The main idea of the experiment is to combine a varying input u and observe this effect on the output y as shown in Equation 1.

$$Z^N = \{[u(t), y(t)], T = 1, \dots, N\} \quad (1)$$

After that, select the structure model including structure selection and noise modeling. In this study, we choose Multilayer Perceptron (MLP) for structure selection and ANN with Levenberg Marquardt algorithm for noise modeling. The estimation of parameter a model candidate pairs is expressed in Equation 2.

$$y(t) = y'(t | \theta) + e(t) = g[t, \theta] + e(t) \quad (2)$$

The purposes of training are to get a mapping the data pair with candidate models pair as shown by $Z^N \rightarrow \theta$. The data scaling is required to accelerate convergence during training process in ANN method. The average errors from training results between the output process and output targets is calculated using a *Root Mean Square Error* (RMSE). The success of training process was not only examined by RMSE, but in this study we need to compute the value of *Variance Accounted For* (VAF) with the formula given in Equation 3.

$$VAF = \left\{ 1 - \frac{\text{var}[y(t) - y'(t)]}{\text{var}[y(t)]} \right\} \quad (3)$$

where, $y(t)$ and $y'(t)$ are experimental input and output variable values.

3. Results and Discussion

Figures 3 and 4 show the input and output variables of GCRs on the ground based Neutron Monitor for 12 years data obtained from Inuvik station (with target output is Corr and Press). The input variable in this study is Corr, Press and Uncorr) from the Fort Smith station.

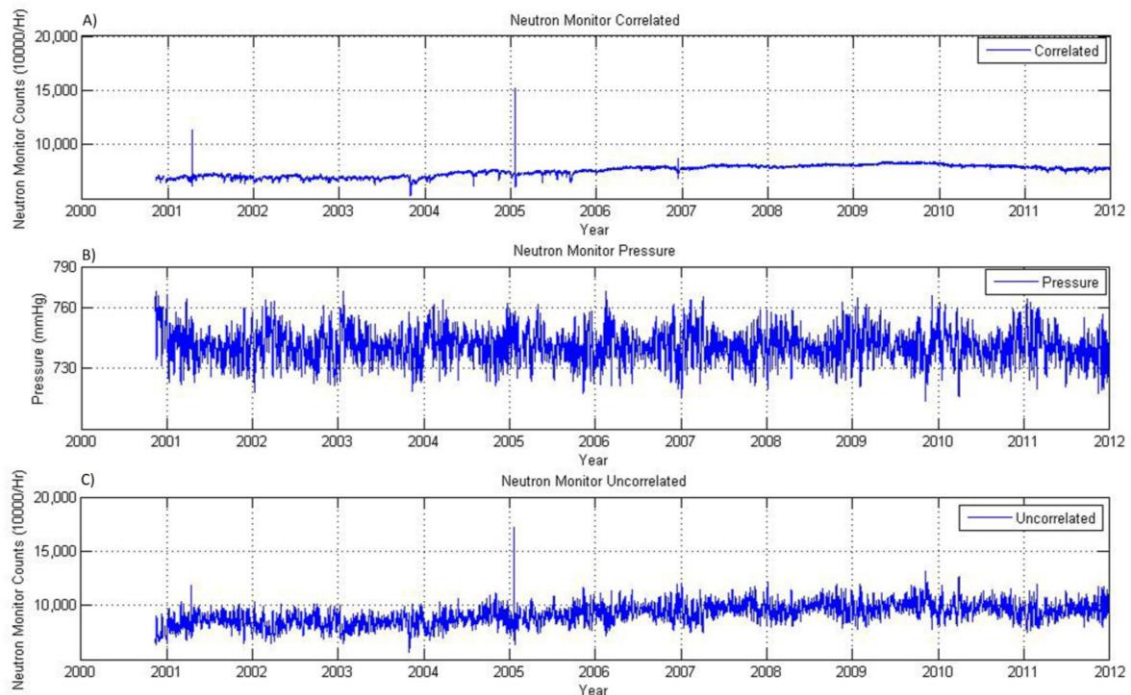


Figure 3. Data input for modelling soft GCR sensor from Fort Smith area for data (a) Corr, (b) Press and (c) Uncorr

As shown in the figure, data input on January 2000 was missing because neutron monitor in the Fort Smith area was under construction. Therefore, in the training process a missing data (or NaN) should be deleted. The neutron monitors in this area have been developed in October 2000. However, on July 2000, the neutron monitor at Inuvik station was detected too much neutron as shown in Figure 4 (between 2000 and 2002). Because “*The Bastille Day Event*” occurred in July 2000 and “*The Halloween solar storms*” in October 2003, the prominent peak of Corr data was detected a lot of neutron due these solar phenomena, both Fort Smith and Inuvik areas (January 2005).

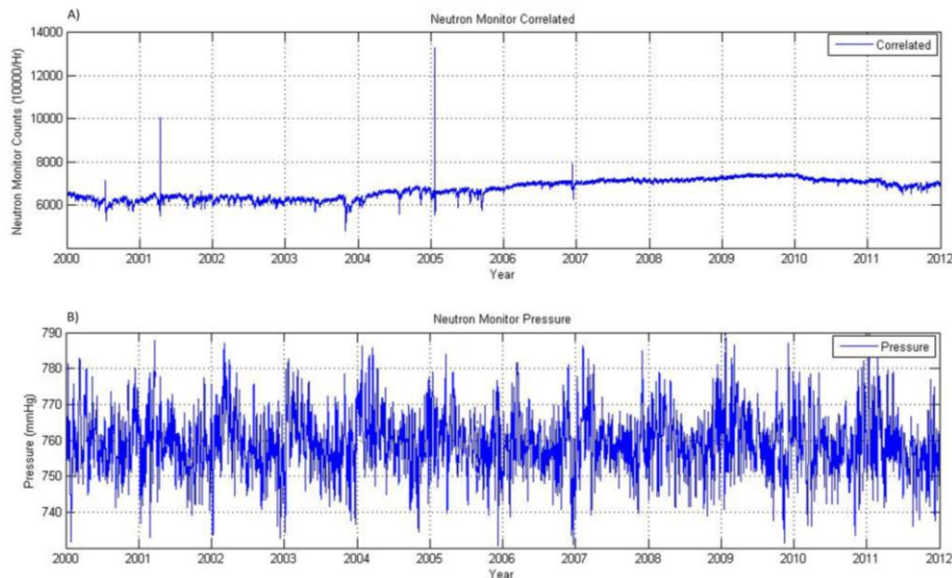


Figure 4. Data output for model at Inuvik area for (a) Corr and (b) Press

In this study, we would to create ground based data based on the ANN model and develop Graphic Utility Interface (GUI) for a soft sensor as shown in Figures 5 and 6. In the training process, we use MLP structure, which have three layers: input, hidden and output.

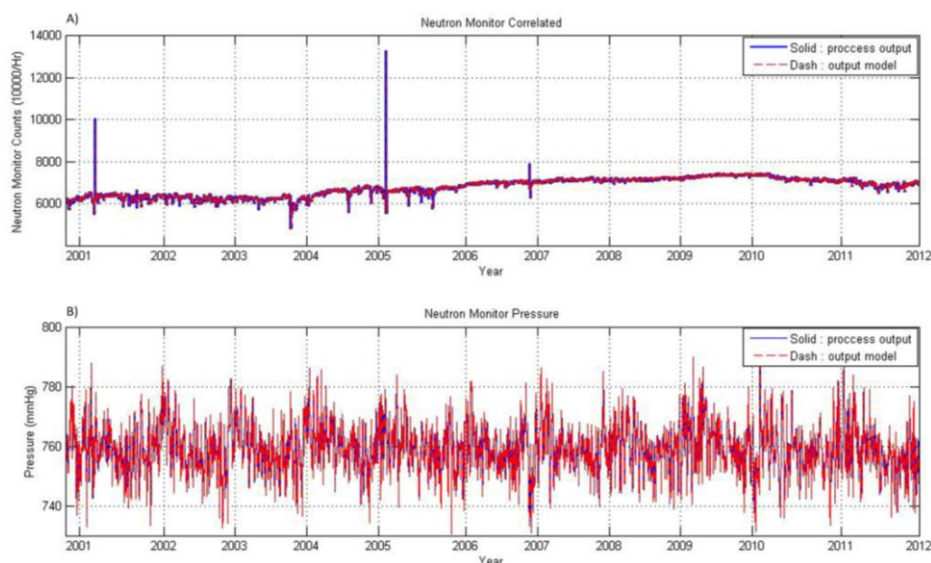


Figure 5. Result of training model based ANN with Levenberg Marquardt algorithm for (a) Corr and (b) Press

As shown in the figure, the red line is result of training and the blue lines are target (output variable). In the result of training process (red line), these line is always tracking on blue line color, this indicate that the training process has been successful and the model has a tendency to follow the pattern of data obtained from target.

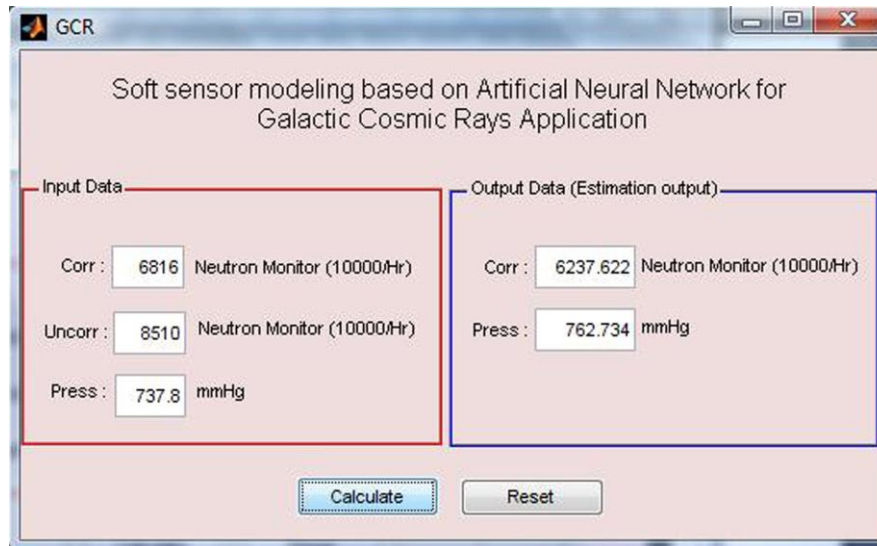


Figure 6. The soft sensors GUI

As shown in the figure, the first step is to develop a soft sensors GUI are by inserting in command window Matlab software *guide* and choose GUI with Uicontrols. The second steps, put all functions at training section to calculate button and the last step create some functions to clear edit text on red and blue box with reset button. The red box is input data and blue box is result of estimation from input variable. For example we choose corr 6816 Neutron Monitor (10^4 /Hour), uncorr 8510 Neutron Monitor (10^4 /Hour) and press 737.8 mmHg (see Table 1, Column 3). The result of estimation input variable is corr 6237.622 Neutron Monitor (10^4 /Hour) and press 762.734 mmHg. We use *three* hidden layer and *linear* activation function on construction of hidden layer. The reason is based on the value of iteration, *Root Mean Square Error* (RMSE) and *Variance Accounted For* (VAF) in the training process as shown Table 3 and Table 4.

Table 3. Iteration result

Iteration	Weight
1.	7.216e-003
2.	3.681e-005
3.	4.388e-006
4.	4.236e-006
5.	4.199e-006
6.	4.185e-006
7.	4.176e-006
8.	4.173e-006
9.	4.165e-006
10.	4.164e-006
11.	4.164e-006
12.	4.164e-006
13.	4.164e-006
14.	4.164e-006

Table 4. RMSE, VAF and Percent error result

Output Model	Result		
	RMSE	VAF (%)	Percent error (%)
Corr	3.8670e-004	99.9839	0.133
Press	1.3414e-004	99.9831	0.014

4. Conclusion

We had successful developed a soft sensor based on the Artificial Neural Network (ANN) model from ground based Neutron Monitor data. The soft sensor to simulate of Galactic Cosmic Rays (GCRs) using the 12 years data and is performed with Matlab Graphic Utility Interface (GUI) software. In the training process, we use Multilayer Perceptron (MLP) structure that to have three layers. The result on training process from ANN model is examined using *Root Mean Square Error* (RMSE) and *Variance Accounted For* (VAF). The maximum percent error values are 0.133% and 0.014% for Corr and Press, respectively. From this results showed that the soft sensor developed showed with high accuracy and capable to be used for GCRs estimation. The next study we will to do a modeling of GCRs radiation for a satellite application in the equatorial region like Near Equatorial Orbit (NEqO) to assess the GCRs impact on our spacecraft.

Acknowledgments

This research is supported by Ministry of Education Malaysia (MoE) under grant FRGS/2/2013/SG03/UKM/02/3. The authors would like thank Bartol University for providing data used in this study, and Matlab forums for advising in Matlab GUI programming under Windows platform.

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