Hardware Implementation for the Atmospheric Temperature Vertical Profiles Inversion from Satellite Data

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A new sensor is developed for estimating the vertical atmospheric temperature profiles. The inferred data are obtained by an implementation of an Artificial Neural Network (ANN) on hardware device. Such neural-computer is configured by using VHDL (Very High speed integrated circuit hardware Description Language). The methodology is based on an inverse procedure from satellite data retrieval, where a Multilayer Perceptron (MLP) network is trained using data provided by the direct model characterized by the Radiative Transfer Equation (RTE). In addition, real radiation data from the HIRS-2 (High Resolution Infrared Radiation Sounder) is used as input for the ANN to generate temperature profiles that are compared to the measured temperature profiles from radiosonde. The generated profiles reveal better estimations, from those results obtained with regularized inversions. The advantages of using ANN based systems are related to their intrinsic features of parallelism; much faster than regularized approaches; and the inversion procedure can be implemented in hardware device – allowing an on-board application in the satellite.

The retrieval of atmospheric temperature profiles from satellite radiance data became important for applications such as weather analyses and data assimilation in numerical weather predictions models. Interpretation of satellite radiances in terms of meteorological parameters requires the inversion of the RTE, where measurements of radiation performed in different frequencies are related to the energy from different atmospheric regions. The degree of indetermination is associated with the spectral resolution and the number of spectral channels. Moreover, usually this solution is very unstable regarding the noises in the measuring process (Rodgers, 1976). Also, several methodologies and models have been developed to improve the satellite data processing. Due to the difficulty of obtaining correct RTE solutions, several approaches and methods were developed to extract information from satellite data (Liou, 1982). The atmospheric temperature estimation is a classical inverse problem. In order to deal with the ill-posed characteristic of the inverse problem, regularized solutions have been proposed (Tikhonov & Arsenin, 1977; Campos Velho & Ramos, 1997). Recently ANN solutions have also been employed for solving inverse problems. In this work an ANN is implemented in a hardware description language to be implemented in a FPGA (Field Program Gateway Away) device, solving the inversion of remotely sensed data. The temperature retrievals of the technique are compared to the ones obtained by Ramos et al. (1999) and Carvalho et al. (2000), where Tikhonov and maximum entropy principle regularization techniques were used.

The radiative transfer process can be modeled using the linear integro-differential Boltzamnn equation. However, depending on the range of satellite observation – infrared, in this case – the RTE can be simplified. The Schwarzchild's equation is a RTE version where the scattering phenomenon can be neglected. The atmosphere is modeled as a black body, following the Plank's law, relating the radiances with the body temperature. The mathematical formulation of the direct problem that permits the calculation of radiance values from associated temperatures is (Liou, 1982):

$$I_\lambda(0) = B_\lambda(T_s)\Im_\lambda(p_s) + \int_{p_s}^{0} B_{\lambda i}[T(p)]\frac{\partial \Im_\lambda(p)}{\partial p}dp \tag{1}$$

where, I_λ is the value of the spectral radiance, subscript s denotes surface; λ is the channel wavelength; p is the considered pressure; $\Im$ is the space atmospheric layer transmittance function that is a function of the wavelength and the concentration of absorbent gas, which usually declines exponentially with the height. B is Planck's function (Equation 2), which is a function of the temperature T and the wavelength λ:

$$B_\lambda(T) = \frac{2hc^2/\lambda^5}{\left[e^{hc/k_B\lambda T} - 1\right]} \tag{2}$$

h is Planck's constant; c is the light speed; and k_B is Boltzmann's constant. The pressure is used as a vertical coordinate, due to the linear relationship between these two quantities (hydrostatic equation): $p = -g\rho z$; being g the gavity, ρ the air density, and z the height above the ground. This simplified RTE was employed in the training, validation and generalization tests. The methodology was tested with 324 profiles of TIGR database, more details can be found in Shiguemori et al. (2006).

Real satellite radiance data, from the HIRS-2 of NOAA-14 satellite, were used to evaluate the performance of the MLP. The HIRS-2 is one of the three instruments of the TIROS Operational Vertical Sounder (TOVS). The data were obtained during Satellite Launching Vehicle (VLS) campaign. The vertical atmospheric temperature was obtained by radiossonding realized in October 27, 1997, 14:58 pm in Alcântara-Maranhão State Brazil. This choice was done because the sky was clean and it was synchronized with NOAA-14 satellite passing at the same location (Carvalho et al., 2000). The number of observations corresponds to a fraction of the number of temperatures to be estimated. For instance, in the example presented hereafter, 40 temperature values are estimated from 7 radiance measurements. Figure 1 shows the comparison of regularization methods, Matlab and VHDL implementation results. In Figure 1-a, the ANN result is compared with Tikhonov order-1 and Maximum Entropy order-2 regularization methods (Carvalho et al., 2000). Figure 1-b shows the comparison of MatLab and VHDL implementations. Finally, in Figure 1-c the error profiles of the retrievals are compared.

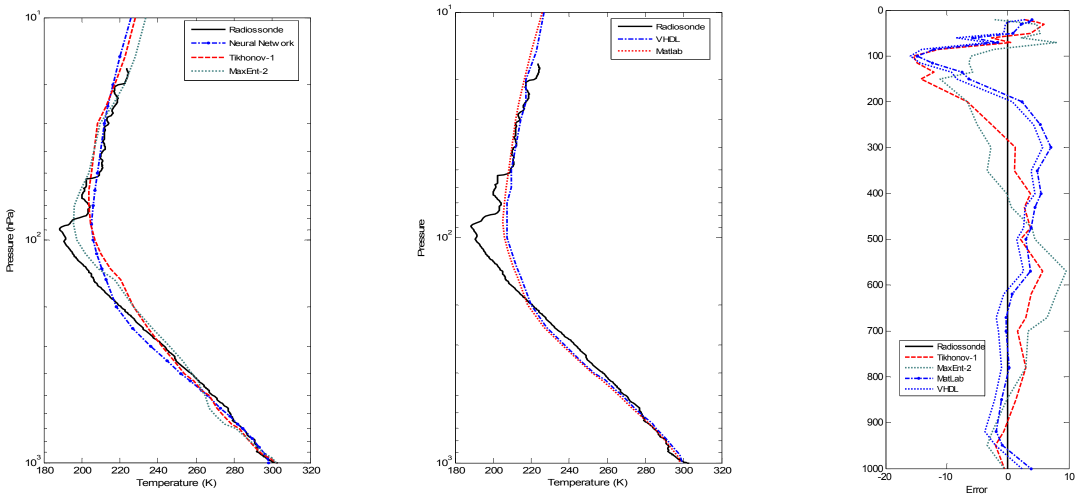

Figure 1 – (a) Comparison of radiossonde, regularization methods and networks results, (b) comparison of MatLab and VHDL retrievals, (c) errors of retrievals.

The implementation was effective for solving this inverse problem, and the reconstructions are comparable with those obtained with regularization methods (Ramos et al., 1999; Carvalho et al., 2000), even for data containing noise. Some advantages can be listed with the use of the implementation: after the training phase, the inversion with ANNs is much faster than the regularization methods; it is an intrinsically parallel algorithm; finally, ANNs can be implemented in hardware devices, becoming the inversion processing faster than ANNs emulated by software and possibility to on-boarding in a satellite. The ANNs can be inaccurate if they are extrapolated to cases outside the training domain, however the use of ANNs technique can provide good solutions when the training phase encompasses the domain of the potential solutions to the real problem.

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