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A new algorithm on increasing the sensitivity of microwave radiometer based on nonlinear prediction

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Abstract

Currently, microwave radiometer, which has been one of the most important remote sensors in the land, ocean or atmosphere remote sensing, has played a vital role in space exploration such as the lunar exploration in China. As a passive remote sensor, microwave radiometer receives the noise resembling signals that are generated by microwave radiation while mixed with the systemic noise of the receiver. Therefore, it is the significant subject that how to improve the sensitivity of microwave radiometer that people devotes to study. And on the system noise reduction lies the key. So far, except through choosing low noise element to the receiver, there is no effective alternative to remove the influence of the systemic noise on output uncertainty of microwave radiometer. However, for the purpose of providing or inspiring solution to this problem, this paper inquires into the application of nonlinear predictive method in predication the systemic noise of microwave radiometer. As the substance of the method, neural network shows its function on reducing the systemic noise effectively by estimating and predicating it. Because neural network can improve the estimated precision when estimating the systemic noise, after the noise passes through filter, certain random characters are lost while determinacy are presented to some extent. In fact, the more narrow filter band is, the smaller predictive error will be. The results are of assistance in understanding the intrinsic quality of the systemic noise and offer a new way for improving property of microwave radiometer.

Keywords: Nonlinear prediction; Microwave radiometer; Neural network

1. Introduction

Microwave radiometer is the one of three kinds of spaceborne instruments. In the developing course of microwave radiometer how the detecting ability of its weak signal is improved is a task by study hard all along. In 1946, Dicke overcame the influence of gain fluctuation on the system stability, which made microwave radiometer be practical (Dicke, 1946). In 1967, Goggins developed a microwave feedback radiometer, which made the microwave radiometer is insensitive to system gain fluctuation (Goggins, 1967). In 1968, Hach let two reference sources whose difference value is known input the system so the fluctuation of the system is detected. And the fluctuation is used for adjusting the gain of behind a amplifier for compensating system gain fluctuation (Hach, 1968). Since the 1990's the computer gain compensatory and continuously calibrated technique are developed, therefore microwave radiometer is improved very much at stability, weigh, volume and power consumption (Junrong; Jing; Amiot and Goldstein, 2007; Misra et al., 2002; Brown et al., 2007; Hui et al., 2007). Above-mentioned technique to be aimed mainly at system gain fluctuation on the output fluctuation of microwave radiometer in above-mentioned technique some appropriately compensatory measures are used for improving the detecting weak signal ability of microwave radiometer. However at reducing the fluctuation of receiver noise and improving the microwave radiometer sensitivity mainly is determined by the front-end devices. So far there is not a very valid method that can make insensitive to receiver noise fluctuation.

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In recent years, the applied study of the theory about nonlinear predication has been paid widespread attention. On the basis of the theory of phase space reconstruction nonlinear time series analysis researches the characters of phase space dynamics and then the predication is done. Since the 1980's nonlinear time series analysis has made better program at algorithm and predication research. The models of local predication, global predication, neural network predication and fusion predication on the basis of radial basis functions have been developed (Qiansheng et al., 2000). Nonlinear predication can not only test the nonlinear behaviors in time series but also can test directly the determinacy in the time series (Wayland et al., 1993). Nonlinear time series predication has been used for the predication of sea clutter and stock market whose models are described by stochastic models before. The results is satisfactory (Li et al., 1994; Leung, 1993; Chakravarthi et al., 1997; Zhaocai et al., 1999; Tiuri, 1964; Ulaby et al., 1981; Proggio, 1990; Fei and Junrong, 1999; Jian-chang, 2004; Wu-fu et al., 2005).

Because of the fluctuation of receiver noise on the microwave radiometer output fluctuation in this paper the theory and method of the nonlinear predication are adopted. The neural network is adopted as the predication model of the microwave radiometer receiver noise.

2. Algorithm description

Microwave radiometer receives more than absolute zero radial electromagnetic energy at microwave regions. The radial energy is similar noise and is mixed with the receiver noise, which form systemic noise. The sensitivity of total-power microwave radiometer is defined as the input signal power that is corresponding to the output voltage fluctuations by system noise (Li et al., 1994), that is, the root mean squared system noise uncertainty. It is expressed as:

$$\Delta T_{\mathrm{N}} = T_{\mathrm{SYS}}/\sqrt{B\tau}, \tag{1}$$

where $T_{\mathrm{SYS}} = T_{\mathrm{A}} + T_{\mathrm{REC}}$ is system noise temperature, T_{A} is noise temperature from antenna, T_{REC} is receiver noise temperature, B is bandwidth of microwave radiometer, τ is integral time of low pass filter. From formula (1) it is seen that T_{A} in the system noise is a detected measure and although the sensitivity can be improved by taking wider B and larger τ, because of the restriction on technology and processing in real the values of B and τ must be appropriate. For a determined system B and τ are fixed. Therefore to reduce the receiver noise temperature T_{REC} is valid way to improve the sensitivity of microwave radiometer.

Microwave radiometer noise can be reduced either using low-noise amplifier or integrating over a long time period. Microwave radiometer noise approximately equals to the equivalent noise temperature of the radio-frequency amplifier (Ulaby et al., 1981). The equivalent noise model of the radio-frequency amplifier has the bandwidth of the radio-frequency amplifier and accords with Gauss distribution. The model can be regarded as a time series. The time series can be predicated by constructing an appropriate neural network model.

In this paper radial basis function neural network is selected as predication model of receiver noise. The researched prediction results that the neural network can predict the receiver noise time series. The radial basis function neural network consists of an input layer, a hidden layer and an output layer. The output function $\hat{f}(\mathbf{x})$ of its predication model is expressed as following:

$$\hat{f}(\mathbf{x}) = \sum_{j=1}^{N_c} w_j \phi_j(\|\mathbf{x} - \mathbf{c}_j\|), \tag{2}$$

where $\phi(r){:}R^+ \to R$ is radial basis function (Chakravarthi et al., 1997), using the popular Gauss function, that is, $\phi(r) = \exp(-r^2/\sigma_p^2)$, $\|\cdot\|$ is the Euclid distance, $w_j (j = 1,2,\ldots,N_c)$ are weight vectors, $\mathbf{c}_j (j = 1,2,\ldots,N_c)$, the center of radial basis function, are actually the vectors of sample space which have same dimension, N_c is the number of the junction points in the hidden layer, σ_p, a selective parameter, determines the width of the center points which are encircled by the radial basis function. No need to adjusting the weight values, the input layer of the radial basis function neural network can directly transfer the input signal to the junction points of the hidden layer. The junction points of the hidden layer consisted by the radial basis function $\phi(r){:}R^+ \to R$, each junction point of the hidden layer has its own center $\mathbf{c}_j$. The hidden layer can transfer to the output layer by adjusting the weight coefficients, and the transfer function of the output layer is a simple linear function. The learning process of the radial basis function neural network prediction model can be divided into two independent steps: the first step is to select a suitable center for each hidden layer; the second step is to minimize the deference between the output value and the expected value by adjusting w_j and σ_p.

The predication model of the fusion neural network of radial basis function and linear function is constructed by several radial basis functions neural network mentioned above and one linear neural network. This model takes the predication outputs of 5 radial basis functions neural networks as the input of one linear neural network, fusing the predication error of every radial basis function neural network by the linear neural network, and finally a predication result of a time series can be obtained.

A pseudorandom series whose bandwidth is 1000 MHz is generated by computer, which accords with Gauss distribution. The pseudorandom series is exported the simulation model of microwave radiometer in Fei and Junrong (1999). First it is filtered by band pass filter whose intermediate center frequency is 10 GHz and bandwidth is 200 MHz. Second it is mixed. Then it is filtered by band pass filter whose intermediate center frequency is 100 MHz and bandwidth is 200 MHz. An intermediate frequency time series is get. The time series is used to recon-