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Application of Cross-correlation Algorithm in Radio Weak Signal Detection

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***Abstract*—Signal detection in low signal to noise ratio (SNR) is widely concerned .In this paper, an algorithm for weak signals detection based on Cross-correlation analysis is proposed. The simulation results show that this algorithm is a fairly effective method for improving the ratios of signal to noise. Using this algorithm in radio monitoring, we can raise the sensitivity of the monitoring system and extend the regional coverage of the radio base station.**

Keywords-Cross-correlation algorithm; Weak signal detection; Radio spectrum management

I. INTRODUCTION

With the continuous and rapid development of the radio technologies and services, the air signals more and more crowded and complicated; the satellite interference incidents occur from time to time. It brings about a new challenge to the radio frequency spectrum management and monitoring. To strengthen the management and monitor of radio waves, expand the coverage of radio monitoring and improve the sensitivity of the monitoring system, the weak signal detection under low signal-to-noise ratio condition becomes more and more important. Accordingly, a lot of more advanced signal processing methods have been constantly emerging. At present, there are mainly four signal processing methods, which are modern spectrum analysis (maximum entropy spectral analysis, auto-regressive moving average spectral estimation), neural network, fuzzy set theory and wavelet analytic method [1,2].

The usual methods of weak signal detection, such as low-frequency and phase-sensitive filtering, require a certain prior knowledge of the signal, that is to say we must know some information of the signal first, such as frequency, phase, etc.. However, it cannot be achieved in the application of monitoring the satellite signal interference; other measures are of high complexity and heavy calculation to varying degrees. In view of this situation, we proposed a new method to detect unknown weak signals in the satellite applications. This method is based on cross-correlation algorithm [3,4], which does not require prior knowledge of the signal, only resorts to the features of signal to filter noise and detect whether the unknown signal exists. We applied this method to detecting signals from data measured in the field; the results indicate its effectiveness.

II. THEORY

The cross-correlation function can be used to detect the signals hidden in the ambient noise; moreover the signal may not have a cyclic pattern, while the autocorrelation analysis cannot separate the random signal from the ambient noise. Specifically, the cross-correlation function of a random signal can be obtained from its characteristics; as for periodic signals, under any conditions of given input SNR and sample record length, the output SNR obtained by the cross-correlation function is better than that obtained by autocorrelation function [5].

The cross-correlation detection is to perform the cross-correlation function operations on the signals (mixed with the noises) to be detected and the reference signals in order to eliminate certain noises. The signal to be detected, $f_1(t)$, and the reference signal, $f_2(t)$, can be expressed as

$$f_1(t) = s_1(t) + n_1(t) \tag{1}$$

$$f_2(t) = s_2(t) + n_2(t) \tag{2}$$

Where, $s_1(t)$ is the signal carrying information from satellite, $s_2(t)$ is the signal transmitted along the ground, $n_1(t)$ and $n_2(t)$ are noises.

Then the cross-correlation function $R_{12}(\tau)$ is

$$\begin{aligned} R_{12}(\tau) &= \lim_{T\to\infty} \frac{1}{2T}\int_T^T f_1(t) f_2(t-\tau)dt \\ &= \lim_{T\to\infty}[\frac{1}{2T}\int_T^T s_1(t)s_2(t-\tau)dt + \frac{1}{2T}\int_T^T s_1(t)n_2(t-\tau)dt \\ &+ \frac{1}{2T}\int_T^T n_1(t)s_2(t-\tau)dt + \frac{1}{2T}\int_T^T n_1(t)n_2(t-\tau)dt] \\ &= R_{s_1s_2}(\tau) + R_{s_1n_2}(\tau) + R_{n_1s_2}(\tau) + R_{n_1n_2}(\tau) \\ &\approx R_{s_1s_2}(\tau) \end{aligned} \tag{3}$$

Where, $R_{s_1 s_2}(\tau)$ is cross-correlation function of $s_1(t)$ with $s_2(t)$, $R_{s_1 n_2}(\tau)$ is cross-correlation function of $s_1(t)$ with $n_2(t)$, $R_{n_1 s_2}(\tau)$ is cross-correlation function of $n_1(t)$ with $s_2(t)$, $R_{n_1 n_2}(\tau)$ is cross-correlation function of $n_1(t)$ with $n_2(t)$.

Note that $s_1(t)$ and $n_2(t)$, $n_1(t)$ and $s_2(t)$, $n_1(t)$ and $n_2(t)$ are independent random process, their cross-correlation function tend to be zero along with the integration time extension.

Considering the lag-time between the two signals, we can also be obtained it by evaluating the cross-correlation between the two signals. When two signals have a certain lag-time, a peak occurs in the cross-correlation function when the lag time is equal to the lag-time or integral multiple of the lag-time.

III. SIMULATION

We applied this method to detecting signals from data measured in the monitoring field. Its realization structural diagram is shown in Figure 1. The two data flows received from satellite repeater and ground diffraction wave are stored and IF filtered in sequence, respectively. Obviously, the two signals have different transmission distance and the satellite repeater signal lags to the ground diffraction signal. Therefore, delay compensation should be added to the later before carrying out cross-correlation operation. According to specific application, we can calculate that the transmission delay is in the range of 0.1-0.3 second. In order to improve the synchronization of two signals, supposing delay time is 0.2 second, we have taken 0.2 second delay compensation for the ground diffraction signal during the calculating course.

The modulation pattern of signals obtained form monitoring system is DSB modulation. The parameters of two signals sources in simulation are shown in Table 1. The Simulation results are given in the following figures in which the spectrum (horizontal axis) are measured in Hz and the correlation functions in time domain are in second units; while the amplitude (vertical axis) units in Figure 2,3 are dBV and the others are $(\text{dBV})^2$.

Table 1 Simulation parameters

Signal	DSB Modulation signal
FFT Points	1024
Carrier Frequency (Hz)	13M
Band width (Hz)	500K
sampling rate (Hz)	30M

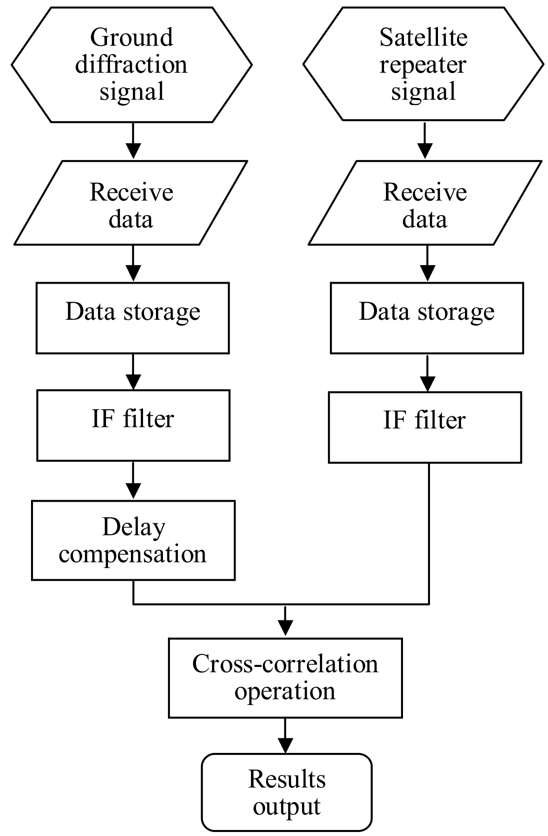

Figure1. Structural diagram of cross-correlation detection.

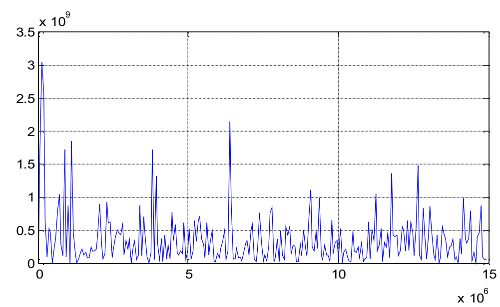

Figure 2. Spectrum of ground diffraction signal.

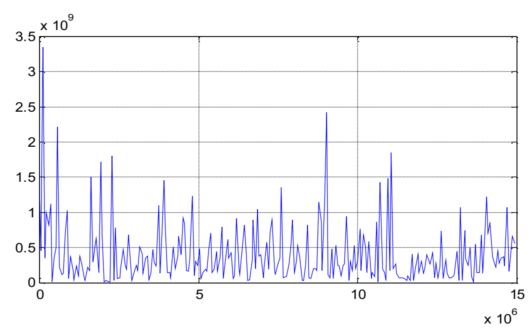

Figure 3. Spectrum of satellite repeater signal.

Figure 2 describes the spectrum of microwave diffraction signals transmitted from the ground diffraction which the receiver received directly. Figure 3 describes the spectrum of signals transmitted by satellite which the receiver receives. Applying the cross-correlation algorithm to the two signals, the simulation results are shown in Figure 4 and Figure 5 when correlation length is 10000; the simulation results are shown in figure6 and Figure7 when correlation length is 30000.

As mentioned above, Figure 4 describes the correlation function in time domain when correlation length is 10000. Figure 5 describes the correlation function spectrum when correlation length is 10000. In figure 4, cross-correlation peak occurs at 0.1ms, so we know that ground diffraction signal lags 0.1ms to satellite repeater signal. Comparing Figure 5 with Figure2 and Figure 3, we can know that the ratio of signal to noise has been improved in very large extent after using cross-correlation algorithm.

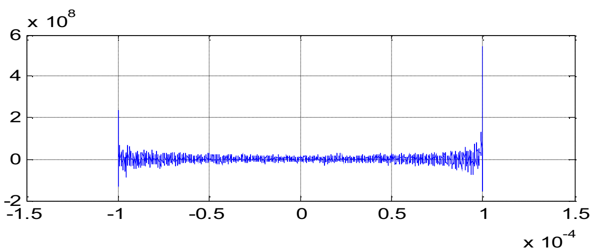

Figure 4. Correlation function in time domain for correlation length 10000.

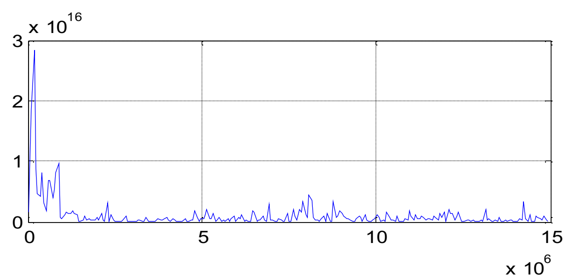

Figure 5. Correlation function spectrum for correlation length 10000.

To investigate the effect of correlation length on monitoring sensitivity, we take different correlation lengths in simulation. The correlation function in time domain and its spectrum are shown in Figure 6 and Figure 7, respectively, when the correlation length is 30000. Comparing Figure 7 with Figure 5, we can see that the longer the correlation length, the better the effect of the spectrum and the smoother the noise.

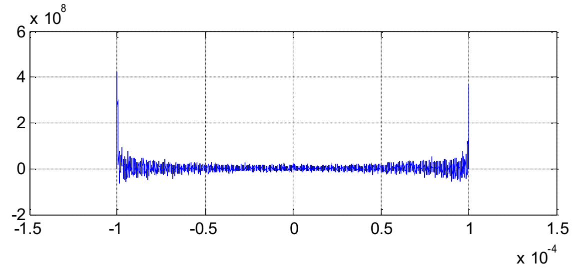

Figure 6. Correlation function in time domain for correlation length 30000.

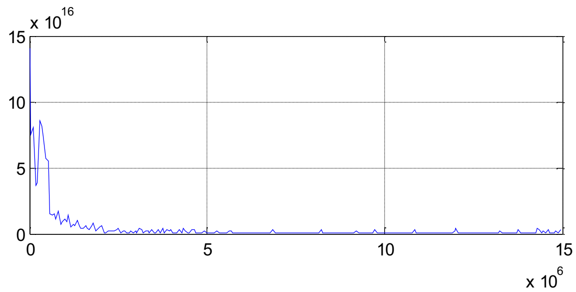

Figure 7. Correlation function spectrum for correlation length 30000.

IV. CONCLUSION

The simulation results show that the spectrum of the cross-correlation function signal is better after the weak radio has been carried on the cross-correlation algorithm and the quality of the signal has been improved. Therefore, with a relatively simple signal processing and high speed calculating, the algorithm can used in the radio monitoring field to increase the sensitivity of the detection system and expand the coverage of the radio monitoring for base stations.

REFERENCES

[1] T. Blu and M. Unser, "Harmonic Spline Series Representation of Scaling Functions", Proceedings of SPIE Applications in Signal and Image Processing, Bellingham: SPIE Press, 2003, 120-124.

[2] B. Moulin, "Identification of Nonlinear Aeroelastic and Aeroservoelastic Systems Using High-Order Iterative Technique", 47th AIAA Guidance, Navigation, and Control Conference, Newport: American Institute of Aeronautics and Astronautics Press, 2006, 1-16.

[3] S. M. Kay, Fundamentals of Statistical Signal Processing, Volume I: Estimation Theory. Beijing: China Machine Press, 2003.

[4] T. Moore and B. Sadler, "Maximum-Likelihood Estimation and Scoring under Parametric Constraints", Army Research Lab, Aldelphi, MD, Tech. Rep. ARL-TR-3805, 2006.

[5] M. L. Meeks, "Methods of Experimental Physics", Academic Press, 2001, 12 (4): 669-705.