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Summary of Weak Signal Detection and Processing Methods

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Abstract. Weak signal detection is a multidisciplinary application of detection methods, which through the use of different methods to study and analyze the statistical properties of signal and noise and use a variety of signal processing methods to analyze and process the input signal. Weak signals can be detected from strong noise to meet the requirements of modern scientific research and application of technology required for sophisticated detection technology. This paper describes the characteristics of weak signal detection and introduces the weak signal detection methods of linear and non-linear theory respectively. The emphasis is on comparing the current methods used in weak signal detection technology summarizing the characteristics of each method. Finally, is the development trend of weak signal detection.

1. Introduction

Weak signal detection features are as follows:

(1) the signal to noise ratio [1] of weak signal detected is relatively low. On the one hand is the signal characteristics of the measured signal itself is very weak; on the other hand, is a strong noise interference. Such as mechanical equipment failure [2] is at an early stage, the failure caused by the various types of signals often mix with other characteristics of the source signal in some special way. Resulting in the characteristic signal becomes weak relatively; If the equipment is running, the signal is also mixed with strong noise's interference.

(2) signal detection with fast and real-time requirements. In practice, signals need to be collected and analyzed but the length of data or the duration of the acquisition process is limited, such as collecting weak signals in the areas of pipeline leakage, communications facilities, seismic testing, industrial surveying and real-time monitoring of mechanical systems. The length of collected data is short, so the rapidity and real-time testing have certain requirements.

With the development of science and technology weak signal detection methods are also changing with each passing day. The traditional weak signal detection methods include correlation detection sampling integration time-domain averaging and spectrum analysis. The newly developed weak signal detection methods are adaptive filtering chaotic oscillator neural network wavelet analysis and stochastic resonance.

With the deepening of research more and more theories and methods will be used in the field of weak signal detection.

2. Weak Signal Detection Using Linear Theory

2.1 Related Testing

Related tests are mainly to the correlation analysis of signal and noise. The application of self-correlation detection technology is very wide, because the signal is periodic and the noise has no periodicity. The randomness of the noise is very strong. The auto-correlation operation utilizes the difference between the signal and the noise to realize the noise removal. Signal and noise are independent of each other. The definition of auto-correlation function shows that the signal itself has

relevance and the randomness of the noise determines the noise and the signal or the noise is irrelevant.

Corresponding to the auto-correlation law, there is also a cross-correlation law. The latter two algorithms are more powerful in suppressing noise and extracting signals than the latter one. The premise of cross-correlation algorithm is that we must know the repetition period or frequency of the signal to be detected and send out a reference signal at the receiving end. The frequency of the signal is the same as the frequency of the signal to be measured and the correlation between the reference signal and the noisy signal is analyzed.

When applying the linear theory method to detect the weak signal the, most commonly used and the effect is more obvious is the correlation detection method. Integration time and signal bandwidth will affect the related detection. Only under the condition of wide bandwidth and long integration time, the system identification accuracy will be higher.

2.2 Sampling Points and Digital Average

The sampling integral and the digital average are widely used in the fields of chemistry and so on. The periodic signal submerged in the noise can be recovered by sampling integral and digital average method and the effect is obvious. According to the accuracy requirements of the recovery signal, each signal is divided into periods in the sampling process, thus obtaining a number of time intervals. Respectively separate signals are sampled sequentially and then these samples are integrated or averaged signal while ensuring that these signals are in the same period of different periods. The process of sampling integration can be realized by the analog circuit, but the realization of the digital average cannot be realized by the analog circuit and is generally realized by the computer.

It is an effective way to detect known frequency signals sample integrals and digital averages, and the method is equally applicable to signals with complex spectra. If repeated signal acquisition process accompanied by noise, in order to get a higher signal to noise ratio, you need to take a larger average number of times. The greater the average number of operations selected, the more effective the system is and the better the signal to noise ratio is.

2.3 Time-Frequency Analysis

Time-frequency analysis is a combination of time and frequency used to represent the signal, in a two-dimensional time-frequency plane projection of one-dimensional time signal and then analysis the signal in the time domain frequency domain. Time-frequency analysis of the signal to be observed by the combined time and frequency characteristics of a comprehensive reflection of the signal can also be time and frequency domain information revealed, so you can very clearly understand the relationship between the change in the frequency of the signal and the time. Time-frequency analysis of the signal must first establish a distribution function, through which the signal energy density can be described by time and frequency.

The method of short-time Fourier transforms and wavelet transform is the most widely used one in the signal time-frequency analysis. This method has a more obvious advantage that is with a smaller amount of computation. There is a remarkable characteristic of using wavelet transform to analyze the signal that it has resolution and the representation of the local features of the signal is distributed in time-frequency domain.

2.4 Adaptive Filtering

Adaptive filtering is a newly developed filter with optimal parameter adjustment. The characteristic of adaptive filtering is very prominent, to adjust the filter to the optimal filtering state, the system parameters can be adaptive adjusted according to some optimal criterion; it can be realized even without a priori statistical knowledge of signal and noise. Even when the statistical characteristics of the input signal change, the filter can adapt itself to the "learning process" by adjusting its own parameters. When the statistical characteristics of the input signal changes, the filter can be adjusted to its optimum parameters of the value of the process which is known as the "tracking process", the process reflects the system could learn and track. As one of the best filtering methods, it has the ability of automatically adapting when the auto-correlation function of signal and noise changes slowly over time, and automatically adjusts the parameter value until it satisfies the minimum mean square error in the system. Adaptive filtering has strong adaptability and excellent

filtering performance which has been widely used in practical engineering, especially in information processing technology is more widely used.

3. Weak Signal Detection Using Nonlinear Theory

3.1 Artificial Neural Networks

In the field of engineering or academic often referred to as the neural network. Artificial neural network is a mathematical model that mimics the structure of neuronal synaptic connections in the brain and processes information. The system is complex and consists of a large number of nodes connected to each other.

Kohonen proposed the neural network can be used as a characteristic filter method for detection and extraction of weak signals in 1977. First of all, the system is trained and studied and the background noise without useful signal is taken as the input of the system. Through a great deal of training and learning process the output of the system tends to zero. Through the previous training and learning process, a series of optimization parameters, input of the system intermittently added weak signal operation, through the system of filtering background noise is effectively removed improving the system's signal to noise ratio.

3.2 Chaos Theory

As a rapidly developing cutting-edge discipline, chaos theory has been hailed as one of the three academic achievements of the last century. Sensitivity to the initial value [6] is a basic characteristic of chaos. Simply speaking, each initial value of the chaotic system has a unique motion track corresponding to it. When the initial value changes slightly of the chaotic system, the orbit will change dramatically. If the initial value of chaotic system is disturbed by a weak signal, because the system has the characteristics of initial sensitivity, we can deduce whether the initial value of the system has changed by observing the change of chaotic orbit and the change. According to the change of orbit detecting weak signals exist which is the theoretical basis of chaos theory applied to weak signal detection. Compared with the general dynamic system, the chaotic trajectory is very special. The equilibrium state [7], the periodic state [8] and the quasi-periodic state [9] are three kinds of steady states that a general deterministic dynamical system possesses. However, the state of chaotic motion is not the same. It is a kind of one that is an unstable and limited exercise confined to a limited area and the orbit never repeats.

3.3 Stochastic Resonance Method

The difference of the stochastic resonance method is that this method uses the noise in the signal processing. In short, the principle of stochastic resonance is to introduce periodic signals and noises into the table nonlinear system. Under the energetic effect of noise and applied periodic signals, the nonlinear system will produce strong periodic vibration and vibration frequency is the same as the applied periodic signal, thus forming a synergistic effect that a part of the noise energy is converted into the energy of the signal, thus improving the system output signal to noise ratio.

4. Summary

The method of using non-linear theory to deal with noise is still a hot spot in the future research direction [11-14], and its application fields will also be expanded more widely. Use a variety of methods combined to give full play to the advantages of different methods of signal processing. When using a combination of methods for signal processing, the advantage of different methods can be fully utilized to achieve the complementary effect, thus overcoming the defects of high detection threshold and poor signal-to-noise improvement ratio when using a single method for signal processing, making the application more extensive.

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