A Review on Different Weak Signal Detection Technologies

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***Abstract*— As technology develops the need for transmission of information over long distance with no errors at faster rate increases. But the signal which carries information loosens its strength when it reaches the destination under the presence of strong background noise. Hence different weak signal detection technologies are developed to detect weak signals in the field of wired, wireless, underground and under water communication. This paper deals with the overview of different weak signal detection approaches in different fields. From the survey it is identified that some combined detection approaches may result better Signal to Noise Ratio.**

Keywords—Weak signal detection, Stochastic resonance (SR), Signal to noise ratio (SNR), Curvelet transform, wavelet transform.

I. INTRODUCTION

In any communication system when information signal is transmitted from source to distant destination the signal will deteriorate due to the addition of noise or interference in each stage of transmission. The large amount of noise will add up with the information signal when it transmits through the channel. The channel may be wired, wireless. The information signal is referred as "weak" because its amplitude level is very much smaller than the noise signal. It is difficult to identify the weak information signal under the effect of strong background noise. In the field of acoustic telemetry systems, warfeilds, radar, sonar, fault diagnosis of mechanical system, earthquake, industrial measurement, underground, underwater communication proper reception of information bearing signals plays important role. Hence a number of weak signal detection approaches are developed which involves time domain and frequency domain approach. These detection approaches aimed at detecting weak information signal under low SNR condition and the approach must be faster and implementable in real time. But, combination of these approaches gives better result. That is high Signal to Noise ratio. This paper focuses on the overview of different traditional and recent weak signal detection approaches, its applications, advantages and drawbacks.

II. WEAK SIGNAL DETECTION APPROACHES

A. Correlation Method

This technique is applicable only to known signal. The received signal is compared with the known transmitted signal to find the similarity between the transmitted and received signal in the presence of noise. The detection method is either based on auto correlation or cross correlation. Noise is random in nature. This unique property of noise allowed, relating the information bearing signal with itself or with known signal. Rabiner et al. [1] proposed auto correlation technique for weak signal detection which is most commonly used in audio signal processing to detect various pitch levels. This helps to maintain same signal energy in all frequencies. The frame size for auto correlation technique can be decided by various adaptive algorithms. Wang et al. [2] developed cross correlation approach in structural damage detection. Inner product vector algorithm uses cross correlation to the vibration response in machineries to find the structural damage. A series of experiments proved that the effect of noise on vibration response measurement is minimum on the application of cross correlation method. Main drawback of correlation detection is based on bandwidth requirement and integration time. High precision is achieved only for wider signal bandwidth and large integration time.

B. Intelligent Time-Frequency Joint Detection Method

Xuanchao Liu et al. [3] presented a new approach of weak signal detection based on time-frequency joint detection with LabVIEW programming. This paper focused on Fast Fourier Transform as a frequency domain approach which is used to find information bearing useful channel and index array function in LabVIEW for determining the exact information. This information is passed through the decision device. Interference from useful signal channel is removed by comparing the signal with decision threshold. The noise which has same amplitude level as information signal are eliminated by passing through smooth filter which has reasonable integration time constant. This approach is simple and flexible for known information signal. Intelligent time-frequency detection technique is mainly used in underground communication. In the field of oil or petroleum extraction, the information is sent from underground to ground via viscous medium. The information is subject to large amount of noise and loosens its strength. In order to extract the information bearing signal from weak received signal Intelligent Time-Frequency Detection method is noble approach.

C. Stochastic Resonance Technology

There are different detection technologies used in under water communication. The classical approaches like energy detection method give poor SNR. Correlation detection method applied only for detecting known signal. Matched filter receiver fails to separate the information signal from noise which has same amplitude. Periodogram method does not applicable for high frequency range. Ji-Shu-Yao et al. [4] proposed one of the highly promising methods of weak signal detection in under water

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 05, May-2019

communication is Stochastic Resonance. Stochastic resonance method along with the detection of weak signal enhances the weak signal.SR uses genetic algorithm for selecting the parameters. Performance of SR systems depends on these selected parameters. The performance is similar to high pass filter. Over damped stochastic resonance system will have one stable state. Hence this technique is not applicable for variable input signal. Yaguo Lei et al. [5] proposed a band pass filtering approach with multiple stable values. This special case of stochastic resonance is called under damped multi stable stochastic resonance which suppresses noise along with fault detection in transmission path. System parameters are optimized by quantum genetic algorithm. Haitao Dong et al. [6] developed an underwater weak signal approach by Matched Stochastic Resonance (MSR). The probability of detecting weak signal from noisy channel can be further increased by this approach. In Matched Stochastic resonance approach computational cost is high. This high computational cost is obtained by matching the non linear system characteristic with the characteristics of noisy received signal. This mathematical approach achieves better SNR compared to traditional Stochastic Resonance approach. Mainly in under water and underground acoustic systems various SR approaches are applicable.

D. Half Bit Method

Jianing wang et al. [7] suggested a new approach namely Half bit method which uses transition of bits to extract useful data from noisy signal. In this technique digital data is divided into two halves as even and odd bits, each with half bit duration. Each half bit is correlated. The technique may use circular correlator or differential correlator. The correlated result is combined to obtain improved SNR. Half bit approach is mainly applicable in capturing digital data from satellites, GPS etc. Differential correlating approach can be applied in prior to Half bit approach in order to minimize the bit transition and to minimize the storage requirement.

E. Curvelet Transform and Cross Validation

In the case of weak signal detection by wavelet transform technique, the result will differ depending on the wavelet basis which is selected. So it is necessary to select appropriate basis function. Chang Wen et al. [8] proposed a multiscale wavelet transform called curvelet transform to overcome the drawback of basic wavelet transform technique. In this approach weak data signal is initially decomposed into subsets by curvelet transform technique. Each subset is parallelly processed by Graphics Processing Unit (GPU). The Signal to Noise ratio is improved by generalized cross validation and genetic algorithm technique. The cross validation technique gives best estimate of received signal. The received weak signal is finally enhanced by adaptive filter. Curvelet transform offers very low probability of error. Jong Woo Shin et al. [9] worked on weak radar signal detect based on Variable band Selection. The paper focused on weak signal detection with multiple frequencies which is processed with Continuous Wavelet transform techniques. In this technique maximum Signal to Noise Ratio is obtained merely by altering scaling factor. In warfeilds, to maintain information security, the operating frequency of signal changed often. The frequency shifting property changes the central frequency. Variation in scaling factor in Continuous Wavelet Transform selects variable bandwidth. A new wavelet analysis approach which works well with high frequency or multiple frequency signals is modified Sinc Wavelet analysis. Here Sinc function is used as mother wavelet which has flat gain.

F. Fast Fourier Transform and Filtering

Jie Wang et al. [10] summarized a traditional technique called Fast Fourier Transform (FFT) which divides data samples into Even and odd component. FFT is found accordingly. The processing time is halved due to the decomposition and processing the signal. The accuracy is improved by adding different window functions. By selecting exact pass band frequency the useful information is extracted by rejecting the noise components.

G. Sparse Decomposition Algorithm

Fourier transform approach applicable only in frequency domain analysis. Wavelet transform technique needs better selection of basis functions for different applications. Mallat et al. [11] proposed a new approach called Sparse Decomposition Algorithm to overcome these problems. It is a linear approach of weak signal detection where information about amplitude, frequency, phases of each component in a weak signal is estimated and compared with actual input. The main drawback of this method is, only sine basis function can be used for best match and large number of computations involved.

H. Lock in Amplifier

Gabal et al. [12] studied signals of AC sensors which are buried with noise. The paper describes Lock in Amplifier which has wide application due to the features of good frequency stability, quality factor and narrow pass band. The Lock in Amplifier has phase sensitive detector which extract the amplitude and phase of information signal by compressing the noise bandwidth. The probability of error is less. The main drawback is known signal must be sine or cosine. This technique is applicable only for single frequency signal.

I. Sample Integral Method

Yu et al. [13] proposed Sample Integral method to detect weak signal. The main principle of this technique involves sampling of the received signal with appropriate intervals. The sampled signal is stored in integrators. Sampling frequency must be high. High Signal to Noise Ratio is achieved by selecting high sampling frequency. This technique is applicable for many analog circuitries to detect weak signal.

J. Hybrid Methods

Different weak signal detection techniques are combined to obtain better weak signal detection result. Y. S. Wang et al. [14] combined approach of wavelet transform and neural network achieve better detection of weak signal which is buried under strong background noise. Initially the received weak signal is sub divided into

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 05, May-2019

TABLE I. SUMMERY OF WEAK SIGNAL DETECTION APPROACHES

Sl.No	Detection Technique	Advantage	Disadvantage
1.	Correlation Detection	• Simple approach for known signal.	• Requires wider bandwidth and large integration time for high precision.
2.	Intelligent Time-Frequency Joint Detection Method	• Simple and flexible approach for known information signal. • Simple structure and flexible control.	• It is required to choose integration time constant reasonably.
3.	Stochastic Resonance Technology	• Better SNR is obtained.	• High computational cost.
4.	Half Bit Method	• Better SNR is obtained. • Less number of computations hence less storage required.	• Large memory requirement. • High searching cost. • Large number of computations involved.
5.	Curvelet Transform and Cross Validation	• Works well with high frequency signal and multi frequency signal. • Provide information security.	• Need to choose basis function wisely according to the application.
6.	Fast Fourier Transform and Filtering	• Processing time is half of the time required for other detection technique. • Accuracy is high.	• Processing time required is high. • Applicable only for smooth continuous signal.
7.	Sparse Decomposition Algorithm	• Linear approach which uses only sine basis function. • Simple approach.	• Large number of computations involved.
8.	Lock in Amplifier	• Good frequency stability, quality factor and narrow pass pand.	• Applicable only for known frequency signal. • Known signal must be single frequency sine or cosine.
9.	Sample Integral Method	• High SNR is obtained by high sampling frequency.	• Applicable only for analog circuits.
10.	Hybrid Approaches	• Better detection result is obtained. • Probability of error is low. • Better Signal to Noise Ratio is obtained.	• Complex compared to individual approaches.

wavelets and processed parallelly. Neural networks are used for feature extraction. Manjula et al. [15] proposed a hybrid method in which the weak signal can be decomposed by Empirical mode decomposition technique and characteristics of noise can be extracted by Hilbert Transform technique. Lv et al. [16] combined wavelet analysis with chaotic oscillator method for better detection. The unknown amplitude is determined by wavelet analysis and unknown frequency is identified by Choatic oscillator technique. This technique is applicable for known signal. Javier et al. [17] combined the correlation method with double coupling Duffing oscillator. The Correlation technique rejects the part of noise signal and remaining signal component is compared with unknown frequency by Double coupling Duffing Oscillator. This combined technique extracts the information signal from weak noise signal.

III. CONCLUSION

In recent era, requirement for secured data transfer and reception of exact data which is being transmitted plays important role. A number of weak signal detection techniques are proposed. Based on review on weak signal detection techniques it has been observed that all proposed approaches has advantage as well as drawbacks. Depending on the application, different weak signal detection approaches can be selected. It has been concluded that combination of different detection approaches gives better Signal to Noise Ratio. The future work involves study and implementation of different hybrid approaches.

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