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Very Low Frequency (VLF) Signal Noise Reduction and Compression using By-Level Wavelet Thresholding

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Abstract

VLF signals have a various characteristics that differ form other types of seismic signal. The properties of VLF signal changes continuously with the properties of propagation medium and it contains substantially large amounts of noise. Due to this traditional compression technique, such as run-length or entropy encoding are not applicable for these types of signals. Different approach is to be used to recognize the reversible signal using less information. Therefore in present paper wavelet transform technique is used for this domain because it is very advanced signal processing method as compare to Fourier transform ,since it captures the time and frequency information effectively. As a result most of the useful data is concentrated into a smaller range values. At this point the data can be thresholded and still retain a high percentage of the "energy" of the signal. In the reconstructed signal minor error introduces due to selection of threshold level and wavelet used. In this paper we used improved By-level wavelet thresholding for the noise reduction and signal compression.

1. Introduction

Most of the signals observed by satellites are generally corrupted by unpredictable noise sources. In many cases satellite signals are adversely influenced by noise, so they cannot be detected and classified correctly, so that pre processing is necessary to reduce the noise as much as possible. Filtering of these types of noises from the observed signal is a key point of any signal processing method. Traditional signal processing techniques such as Fourier and Short time Fourier transform (STFT) are effective in many cases, but they have some limitations and they do not give better results for non-stationary signal such as VLF signal.

Natarajan [1] developed a technique for the removal of random additive noise form signals based on data compression. This technique used the well known property of signal noise that is random noise is hard to compress and also it does not require any prior knowledge of the signal or its noise characteristics which is very essential in traditional filtering technique. Natarajan [2] suggested that it is possible to use any compression technique for signal noise reduction. He used piecewise linear compression for these type of filtering. Jeffryes [3] described the method of seismic data compression. He achieved the data compression by splitting the data in to subsets and applying requantization level to those subsets which depends on a numbers representing the subset and on time. Kiely [4] use sub band coding for seismic data compression system. Huang [5] discuss scenario of using principle component analysis as a foundation for atmospheric data retained and compression of uncelebrated and non-normalized Interferograms. Stromberg [6] used Low bit-rate efficient compression for seismic data. Hedstrom [7]) propose a scheme for data compression designed for Amplitude Modulated Signal Sideband (AM-SSB) Speech signal Time-Frequency masking. An ideal signal compression system focuses on reducing the amount of redundant data while preserving the integrity of signals. In the last few years many signal compression technique based on wavelet transform have been developed [8]-[14].The theory of wavelet is a combination of many independent developments in the fields of pure and applied mathematics [15]-[16], electrical engineering [17], Quantum Physics [18] and Seismic geology [19]. The co-ordination between these fields in the last decades produced many new important and vital wavelet applications such as image and signal compression [20], turbulence [21], human visual System [22] and earthquake prediction [23].

In these work we used wavelet compression technique based on by level thresholding some time known as level dependent thresholding [24]. That method better suited for hardware implementation without compromising on performance. At the end of this paper the effectiveness of these methods is validated by results of analysis on compressed and observed VLF signal.

2. Method and Analysis

Wavelet transform represent a transient or non stationary signal in terms of time and scale distribution. Research shows that it is an excellent tool for on line data compression, analysis and denoising. It has ability to preserve the temporal locality of sharp transition within time domain signal. In wavelet analysis, the basis functions consist of the wavelet scale function, as well as scaled and shifted versions of the mother wavelet function. The scale function in wavelets is used to capture the general (or low detail) information on the signal, whereas different mother wavelet scales are used to capture the details of the signal, with each successive scale capturing (describing) finer and finer levels of detail.

Wavelet analysis uses a time localized oscillatory function as the Mother Wavelet. [25]-[27]

Suppose $x(t)$ denote observed signal and $\psi(t)$ denote wavelet basis function. If $\hat{\psi}(\omega)$ denotes the Fourier transform of $\psi(t)$ and satisfied the following condition:-

$$c_{\psi} = \int_{0}^{\infty} \frac{\left|\hat{\psi}(\omega)\right|^2}{\omega} d\omega < +\infty$$

The wavelet transform of $x(t)$ is written as

$$W_x(s,\tau) = \int_{-\infty}^{+\infty} x(t) \frac{1}{\sqrt{s}} \psi^*\left(\frac{t-\tau}{s}\right)$$

$$s > 0$$

Where s = scale

τ = position

And $\psi^*(t)$ is the conjugate function of $\psi(t)$.

For practical point of view s and τ parameter must be discretized. For a particular class of wavelet the scale parameter s can be sampled along the dyadic sequence $(2^j)_{j\in z}$, and the translational parameter can be sampled as $(k2^j)_{k,j\in z}$, then the discrete wavelet transform can be obtained as

$$\psi_{j,k}(t) = 2^{\frac{-j}{2}} \psi(2^{-j}t - k)$$

Wavelet compression and Level Dependent thresholding:-

The DWT is very useful analysis tool for signal compression. The filter bank of DWT is irregular but approximately regular in the first two or three octaves of sub band decomposition [28]. Data compression methods require that only those wavelet coefficients which carry most of the signal information are identified and retained for use in the reconstruction of the signal [29].

The effective audio signal compression, algorithm use knowledge of the human hearing which is associated with critical bands around a frequency f_m there is masking. A neighbouring frequency with magnitude below a specific threshold is masked by f_m and is not audible to solve this masking problem thresholding is applied. The magnitude of threshold can be calculated by hard and soft thresholding techniques. By applying a hard thresholding the coefficients below these level are zeroed and it is defined [30] by these eqn:-

$$y_{hard} = \begin{cases} d, |d| > thr, thr \geq 0 \\ 0, |d \leq thr| \end{cases}$$

An alternate is soft thresholding at level δ which is chosen for better compression performance and defined by these eqn:-

$$y_{soft} = \begin{cases} sign(d).(|d| - thr), |d| > thr, thr \geq 0 \\ 0, |d| < thr \end{cases}$$

Where d is the wavelet coefficient from the decomposed VLF signal. The variable "*thr"* is the threshold selected. The function y_{hard} and y_{soft} is the wavelet coefficient processed with hard and soft threshold function. *Sign* ( ) is the signum function [31].

This wavelet threholding technique [32] is based on following wavelet selection rule:-

Let as consider the decomposition level J_0 in which Coarsest approximation level is represented by m over 2 and α be the real greater then J_0 and takes the value 1 as suggested by [33].

(a) At level $J_0 + 1$ (and coarse level) everything is kept

(b) For level J from 1 to J_0 , K_J largest coefficient in absolute value are kept using formula $K_J = \frac{m}{(J_0 + 1 - J)}\alpha$.

This algorithm is used to compress VLF signal and compare the quality of the reconstructed signal with observed signal.

The system used for signal compression is shown in Fig. 1 and implemented and simulated to study its performance using Matlab (R2010a). Implementation of this compress algorithm involves three main steps:-

- Wavelet Decomposition: In this step signal is decompose in to selected N levels by choosing proper mother wavelet.
- Thresholding the detail coefficient: for each level from 1 to N a threshold is selected and hard thresholding is applied to the detail coefficients.
- Reconstruction: reconstruction of the signal using the original approximation coefficients of level N and the modified detail coefficients of level from 1 to N.

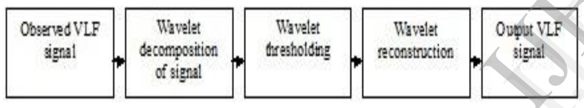

Figure 1 Block diagram of Signal compression algorithm.

For testing the performance of above algorithm three compression parameters are used for the performance analysis of system introduced. They are defined next along with their mathematical expressions.

- Signal to Noise Ratio (SNR)

It is defined as the ratio of signal power to noise power of corresponding signal. Analytically its given by:-

$$SNR = 10\log_{10}\left(\frac{P_{signal}}{P_{noise}}\right) = P_{signal} - P_{noise}(indb)$$

- Creast Factor:

It is calculated from the peak amplitude of the waveform divided by the RMS value of the waveform and analytically given by:-

$$C.F = \frac{|x|_{peak}}{x_{rms}}$$

Where $|x|_{peak}$ = amplitude of waveform

x_{rms} =RMS value of waveform

- Total harmonic distortion:

The total harmonic distortion, or THD, of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequencies.

The VLF signal compressed here are VLF Whistler and Hiss which has been observed by DEMETER satellite during Sep, 2009 at Indonesia. The waveform of these signals with their compressed signal is shown in Fig. 2 and Fig 3.

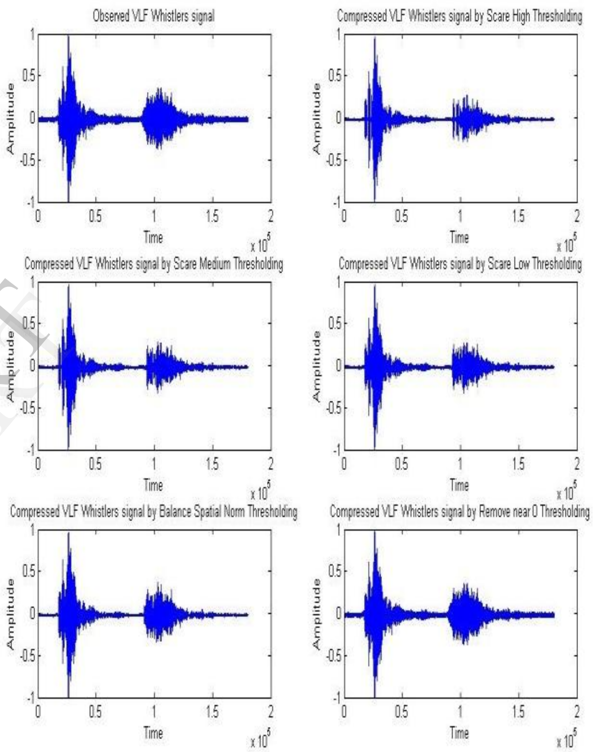

Figure 2 The Waveform of observed and Compressed VLF Whistlers signal.

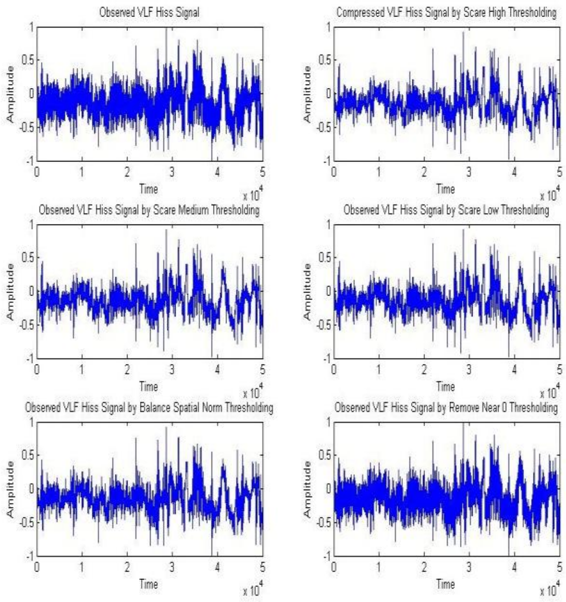

Figure 3 The Waveform of observed and Compressed VLF Hiss signal.

These compressed versions are obtained using “db1” mother wavelet and 50000 numbers of samples. In these analysis different value of SNR, CF and THD are obtained. In this compression process signal obtained are audible and we can still recognized these signals by hearing. During the compression process different thresholding such as Scare high, scare medium, scare low, balance spatial norm and near zero method are applied and tested over a large number of observed signals. In this processes thresholding is applied over a different wavelet coefficients. At this stage required truncate coefficients are obtained. These coefficients are then used to reconstruct the output compressed signal. Different results were obtained allowing efficient evaluations and comparisons of the used methods and parameters.

3. Noise reduction and compression of VLF signal

We conducted experiments using the above mentioned algorithm in Matlab (R2010a). SNR, CF and THD are calculated for each of compressed signal and results are summarized in table (1&2).

Table (1) Performance of By Level Thresholding for VLF Whistlers signal

S. No.	Signal	Thresholding method	Retained Energy	Nos of Zeros	SNR	Crest Factor	THD
1.	Observed	-	-	-	14.42	14.14	80.32%
2.	Compressed	Scare high	72.29%	94.29%	15.03	14.14	75.38%
3.	Compressed	Scare medium	78.08%	92.99%	14.55	13.16	61.20%
4.	Compressed	Scare low	82.50%	91.70%	14.35	13.25	67.59%
5.	Compressed	Balance spl-norm	91.15%	91.80%	13.79	12.56	37.66%
6.	Compressed	Near zero	99.97%	99.97%	14.43	12.01	21.78%

Table (2) Performance of By Level Thresholding for VLF Hiss signal

S. No	Signal	Thresholding method	Retained Energy	Nos of Zeros	SNR	Crest Factor	THD
1.	Observed	-	-	-	24.39	4.27	100%.
2.	Compressed	Scare high	72.29%	94.29%	24.99	4.24	100%
3.	Compressed	Scare medium	78.08%	92.99%	24.90	4.22	100%
4.	Compressed	Scare low	82.50%	91.70%	24.80	4.27	100%
5.	Compressed	Balance spl-norm	91.15%	91.80%	24.04	4.12	100%
6.	Compressed	Near zero	99.97%	99.97%	24.13	4.11	100%

Also, the percentage of zeros (%Z) and percentage of the energy retained (%ER) are included. In these work thresholding is applied on each wavelet coefficient individually but it does not process we retained maximum 99.97% and minimum 72.00% of signal energy using the different thresholding methods. Less coefficients shows high energy and SNR is improved when CF is improved, which shows that if we increased SNR after compression waveform of signal change accordingly. Improved SNR shows the enhancement in signal quality. So by compression it is also possible to filter the signal to remove unwanted noise form signal. It is also clear that the value of THD is decreased after compression and the value of CF is approximately same in most of the cases except scare high method which shows this method is suitable for the compression of VLF signal.

4. Summary

In this paper, the performance of DWT using level dependent thresholding in VLF signal compression is studies. Compression based filtering can be applied in a variety of signal processing problems [33]-[34]It is particularly effective in filtering broad-band signals and when there is no prior knowledge of either the signal or noise characteristics. We presented architecture for noise reduction and compression of VLF signal using a fast and efficient algorithm for based on wavelet compression. From the graphical results, we found that the resulting compressed signal are smooth and give as a better approximation of the original VLF signal. Analysis also shows that the highly compressed signal is obtained without changing the other important parameter of signal. No further enhancements were achieved beyond level 5 decomposition[35]. Calculated value of different parameter is evident while these parameters remain almost constant for all experiments with negligible changes. This shows that the wavelet transform very efficient in VLF signal compression.

Compression is applicable for many kinds of data, but it is still imperative the user has a basic understanding of the thresholding required. Wavelets are a good choice for doing such compression, as evidenced by other applications, such as image compression, and these results. The compression and decompression applications created are a set of capable and robust tools that would be useful for many scientific datasets.

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