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Improving SNR Of Radar Signal Using Wavelet De-Noising Scheme

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Abstract: **The purpose of Radar signal processing is to extract the desired data from radar signals. The accuracy of data available from radar is limited by thermal noise introduced by the radar receiver, echoes from targets of no interest (known as clutter) and extremely generated interference. As a result radar signal processing is also used to enhance signals and to suppress clutter and externally generated signals. In this paper wavelet denoising is used to improve SNR.**

Keyword: Radar, Clutter, Wavelet, Denoising, SNR.

INTRODUCTION

Noise is one of the major factors of signal distortion and is prime reason for careful design of signal processing units. The main problem with noise is that it tends to interface with the signal and distort it. Noise is present everywhere, in every medium and cannot be avoided. Noise is random in nature and so cannot even be modelled except statistically. For a particular application noise can be modelled for and estimated statistically. Noise can be modelled as White noise or Gaussian noise. It has its spectrum throughout the frequency spectrum. So it is quite useless trying to eliminate the noise using filters with some particular cut-off frequency.

A. Signal-to-Noise Ratio

The calculation of the equivalent noise of an amplifier, receiver or device may have one of two purposes or sometimes both. The first purpose is comparison of two kinds of equipment in evaluating their performance. The second is comparison of noise and signal at the same point to ensure that the noise is not excessive. In the second instance, and also when equivalent noise is difficult to obtain, the signal-to-noise ratio (S/N) is very often used. It is defined as the ratio of signal power to noise power at the same point. Signal-to-Noise Ratio gives the fidelity of the desired signal. It is usually measured in dB.

$$\text{SNR} = \frac{\textbf{Average power of message signal at the receiver output}}{\textbf{Average power of noise at the receiver output}}$$

B. De-Noising

De-Noising is the process by which noise is eliminated by processing the signal. In general De-Noising is done by transforming the signal at hand into other domains, process the signal, and then finally reconstruct it back into the time domain. The De-Noising process improves the Signal-to-Noise Ratio of the signal.

I. WAVELETS

A wavelet is a ‘small wave’, which has its energy concentrated in time to give a tool for analysis of transient, non-stationary, or time varying phenomena. The wavelet expansion for a two-parameter system can be shown as

$$\mathbf{f\,(t)=\sum k \sum j \;\; a_{j,k}\, \psi_{j,k}\,(t)}$$

Where both j and k are integer and the $\psi_{j,k}(t)$ are the wavelet expansion functions that usually form an orthogonal basis.
Wavelet transform decomposes signal onto a set of basis functions. These basis functions called wavelets are obtained from a single prototype wavelet by dilations and contractions (scalings) as well as shifts. The prototype wavelet can be thought of as a band pass filter and constant Q property of other wavelets are achieved since they are scaled versions of the prototype. In WT theory, the notation of signal is introduced as an alternative to frequency, leading to time-scale representation, depending on time and scale parameters.

II. WAVELET DE-NOISING SCHEME

In the recent wavelet literature one often encounters the term ‘De-Noising’, describing in an informal way various schemes which attempt to reject noise by damping or thresholding in the wavelet domain. The Thresholding of wavelet coefficient has near optimal noise reduction for many classes of signals. De-Noising differs from filtering schemes in the following aspects:

a) De-Noising does nonlinear filtering i.e., filtering is made as function of some Threshold function.
b) De-Noising tends to optimize the Mean Square Error i.e.,

$$\frac{1}{N}\sum \mathbf{E}\ [\mathbf{f}\ (\mathbf{x_n}) - \mathbf{f}\ (...)]^2$$

Wavelets are used as it provides a whole lot of advantages over Fast Fourier Transform (FFT). Fourier analysis has a serious drawback. In transforming to the frequency domain, time information is lost. When looking at a Fourier transform of a signal, it is impossible to tell when a particular event took place. Wavelet analysis is capable of revealing aspects of data that other signal analysis techniques miss, aspects like trnds, breakdown points, discontinuities in higher derivatives and self-similarity. Furthermore, because it affords a different view of data than those presented by traditional techniques, Wavelet analysis can often compress or De-Noise a signal without appreciable degradation.
The underlying model for the noisy signal is basically of the following form:

$$\mathbf{s(n)=f(n) + \sigma\ e(n)}$$

Where time ‘n’ is equally spaced.

In the simplest model, suppose that e (n) is a Gaussian White Noise N (0, 1) then the noise level is supposed to be equal to 1. The De-Noising objective is to suppress the noise part of the signal s and to recover f.
So the main problem lies in modelling the noise and the noise level. In practical case an exhaustive study is to be done in modelling these and then try to eliminate the noise.

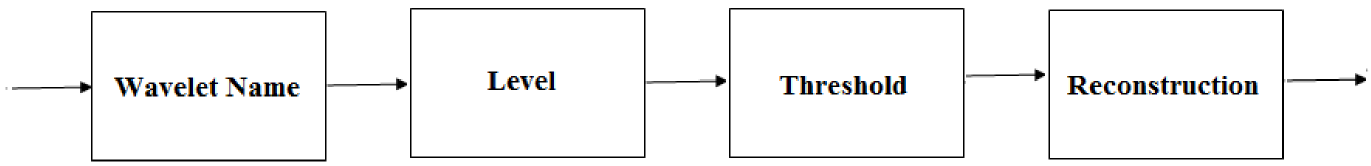

Figure 1: Block Diagram for Wavelet De-Noising Scheme

The wavelet transform provides the time-frequency representation of the signal. (There are other transforms which give this information too, such as STFT, Wigner distribution etc.). This property is used for de-noising which can be achieved in four steps:

Step 1: Selection of Wavelet

There are many types of wavelets available (Haar, Daubechies, Symlets etc....) with different properties among which select one according to the requirement.

Step 2: Obtaining Wavelet Transform Coefficient

Compute the wavelet decomposition of the signal at the selected level N.

Step 3: Selection of Threshold

For each level from 1 to N, select hard or soft Thresholding to the detail coefficients. In addition to these , there are minimaxi, rigrsure, heursure Threshold techniques present. Each of these techniques has a unique behaviour suitable for de-noising a particular type or class of signals.

Step 4: Reconstruction:

Reconstruct the signal using the approximation coefficients of level N and the modified detail coefficients of levels from 1 to N.

III. HARD OR SOFT THRESHOLDING

Hard Thresholding is the simplest method. Hard Thresholding can be described as the usual process of setting to zero the elements whose absolute values are lower than the Threshold. Soft Thresholding is an extension of Hard Thresholding, first setting to zero the elements whose absolute values are lower than the Threshold and then shrinking the non zero coefficients towards o.

A. Thresholding Selection Rules:

According to the basic noise model, four Threshold selection rules can be implemented with the following Threshold return values:

Option	Threshold Selection Rule	Threshold Return
‘rgrsure’	Selection using principle of Stein’s Unbiased Risk Estimate (SURE)	2.0735
‘sqtwolog’	Fixed form Threshold equal to sqrt(2*log(length(s)))	3.7169
‘heursure’	Selection using a mixture of the First two points	3.7169
‘Minimaxi’	Selection using minimax principle	2.2163

B. Thresholding Rescaling:

To deal with unscaled and non-white noise Threshold’s rescaling parameter is used

Option	Corresponding Model
one	Basic Model
sin	Basic Model with Unscaled Noise
min	Basic Model with Non-White Noise

IV. Algorithm for the Calculation of SNR

Generally, as height increases the signal power decreases whereas the noise power increases. Hence it is assumed that the signal-to-noise ratio is a linear function of height. But this need not always be true in the case of atmospheric signals as it depends upon the atmospheric conditions at that particular height. The SNR may vary from maximum to minimum values in a random way but maximum at lower bins when compared to higher bins. The following algorithm can be used for the computation of SNR:

Step 1: Recorder the spectrum $\{P_i, i=0, 1......N-1\}$ in ascending order to form $\{A_i, i=0, 1.......N-1\}$ where $A_i<A_j$ for $i<j$

Step 2: Compute

$$P_n = \sum_{i=0}^{n} \frac{A_i}{(n+i)}$$

$$Q_n = \sum_{i=0}^{n} \frac{A_i^2}{n+1} - P_n^2$$

and if $Q_n > 0$, $R_n = \frac{P_n^2}{(Q_n * M)}$, for n = 1,........N

Where M is the number of spectra that were averaged for obtaining the data.

Step 3:

Noise level (L) = P_k where k= min $\begin{bmatrix} n \text{ such that } Rn > 1 \\ 1. \text{no } n \text{ meets the above criterion} \end{bmatrix}$

Step 4:

Record the spectrum to its correct index of frequency (i.e. $-f_{maximum}$ to $+f_{maximum}$) and subtract noise level L from spectrum

Step 5:

i. Find the index 1 of the peak value in the spectrum

i.e. $\tilde{P}_1 \geq \tilde{P}_i$ for all i=0 ...N-1

ii. Find m, the lower Doppler point of index from the peak point

i.e. $\tilde{p}_i \geq 0$ for all $m \leq i \leq 1$

iii. Find n, the upper Doppler point of index from the peak point

i.e. $\tilde{p}_i \geq 0$ for all $1 \leq i \leq n$

Step 6:

i. The zeroth moment is computed

$$M_0 = \sum_{i=m}^{n} \tilde{P}_i$$

Represents Total power in the Doppler spectrum.

ii. Signal to Noise Ratio (SNR) = $10 \log\left[\frac{M_0}{(N * L)}\right]$ Db

V. CONCLUSIONS

The results shown in this paper were computed for North direction. In this paper we have discussed about improvement of signal to noise ratio of Radar signals using wavelets. SNR is improved by minimizing the noise of signal through wavelet denoising. The improvement is observed by comparing original signal (Figure 2) and denoised signal (Figure 3).

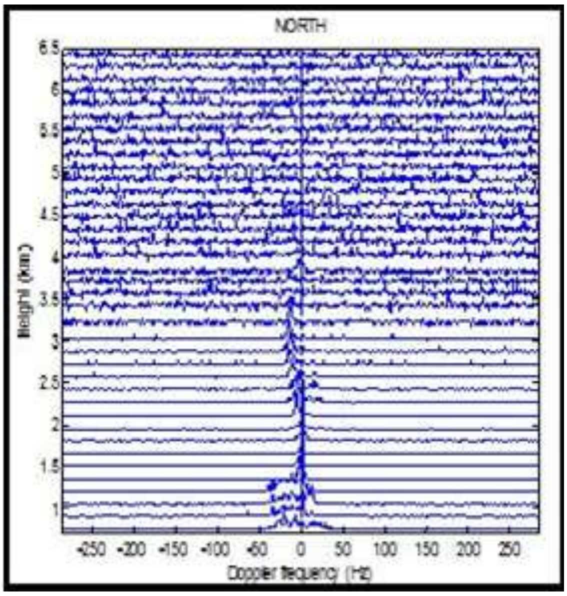

Figure 2: Doppler Profile before De-Noising

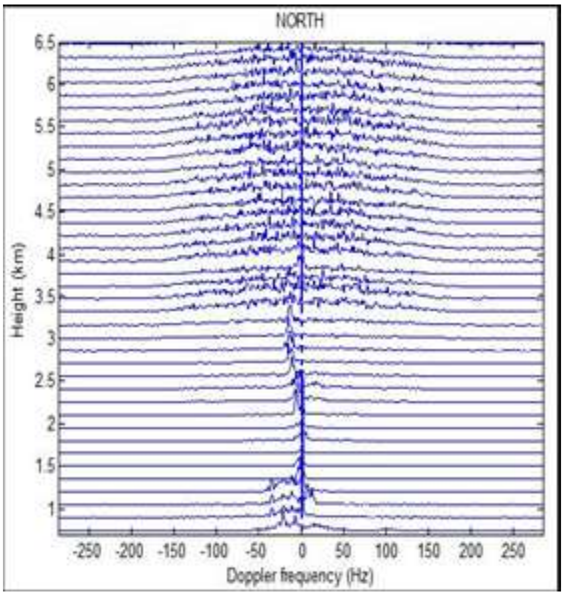

Figure 3: Doppler profile after De-Noising

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