ISSN 2229-5518

Comparison of Signal to Noise Ratio of Lower Atmospheric Wind Profiler Data using Signal Processing Techniques

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Abstract— The main objective of the Lower Atmospheric Wind Profiler (LAWP) is used to identify the atmospheric echoes and estimation of the three spectral moments (i.e., zeroth moment, first moment and second moment) is most important for the study of dynamics and to provide continuous high resolution wind measurements in all weather conditions. The height profile of the wind vector can be improved by detecting the Doppler shift of echoes, so that Signal to Noise Ratio (SNR) may also be improved. At present, we are receiving the LAWP radar data at National Atmospheric Research Laboratory (NARL), Gadanki, India. SNR and doppler shift computation are important parameters in radar signal processing. This paper discusses improvement of doppler shift using Fast Fourier Transforms (FFT), Empirical Mode Decomposition (EMD) and Wavelet Transforms (WT) for LAWP signals. The threshold can detect the fake peaks that are adjacent to the actual signals. In order to get the actual position of the object, those fake peaks should be removed by using Peak Detection Algorithm. SNR for this LAWP data is computed for EMD and Wavelet de-noised signals are compared with the FFT de-noised signals. Results show that there is an effective doppler shift and 21 dB improvement in SNR after de-noising using Db11 wavelet for Lower Atmospheric signals.

Index Terms— Denoisiong, Doppler, EMD, LAWP Signals, Signal to Noise Ratio and Wavelet.

1 Introduction

THE radar works on the principle that when a pulse of electromagnetic waves is transmitted towards a remotely located object, a fraction of the pulse energy is returned through either reflection or scattering, providing information on the object. The time delay with reference to the transmitted pulse and the received signal power provide respectively the range and the radar scattering cross section of the target detected. These classes of radars are known as pulse radars. If the target is in motion when detected, the returned signal is Doppler shifted from the transmitted frequency and the measurement of the Doppler shift provides the line-of-sight velocity of the target. The radars possessing this capability are referred to as pulse Doppler radars. The atmospheric radars of interest to the current study are known as clear air radars and they operate typically in the VHF (30 – 300 MHz) and UHF (300 MHz – 3GHz) bands.

2 Lower Atmospheric Wind Profiler Radar

These Lower Atmospheric Wind Profilers are used for conducting research in the lower atmosphere [1]. National Atmospheric Research Laboratory (NARL) at Gadanki (13.47°N, 79.18°E) near Tirupati, India has been operating this 1280 MHz, atmospheric radar for studying structure and dynamics of the lower atmosphere. These radars employ bi-phase coding (pulse compression) with complementary codes, to achieve better range resolution with maximum average power (height coverage). These radars receive the echoes from the atmosphere in the height range from about 100m to 4-5Km, in clear air, which are very weak and contaminated with clutter. These wind profiler radars are very high sensitive and coherent. It can measure the complete Doppler spectrum of atmospheric targets with a time resolution on the order of 1 min and a range resolution of about 100m. These data may be used to estimate the Moments, Noise Levels and Doppler shifts [2].

LAWP Radar can be employed, in addition to the detection and characterization of soft or distributed targets such as the earth’s atmosphere. There are two wind profiling techniques that are commonly used to determine the three components of velocity vector (Vertical, Zonal and Meriodonal) namely, the Doppler Beam Swinging (DBS) method and Spaced Antenna (SA) method.

The DBS method uses a minimum of three radar beam orientations (Vertical, East-West, and North- South) to derive the three components of the wind vector. The most commonly used technique for wind profiling is the Doppler technique. The profiler computes height by using the time interval between transmission of the pulse and reception of the return signal. However, wind speed and direction are determined by using the Doppler principle.

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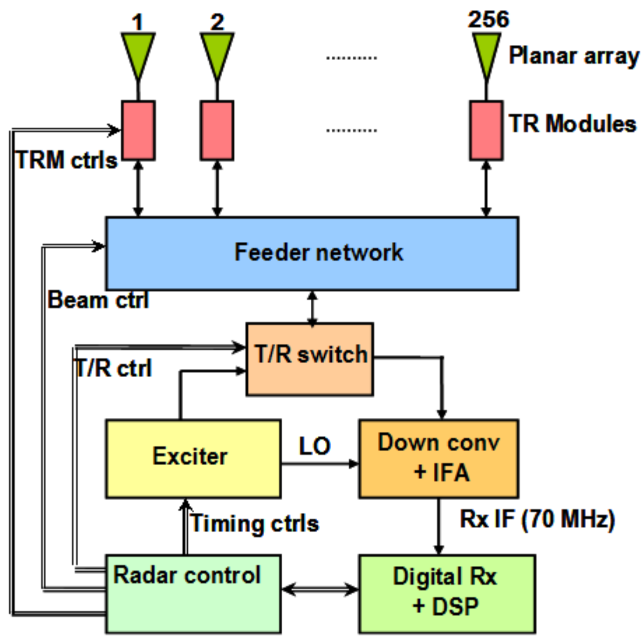

Fig 1: Block diagram of LAWP Radar

LAWP Radar system Specifications:

- Operating frequency is 1280 MHz
- Wind profiling Technique is Doppler Beam Swinging.
- Minimum height range is 100m
- Maximum height range is about 3-6 km in clear air and up to 12 km during precipitation
- Type of Antenna is Active patch array 16 x 16 (2.8m x 2.8m)
- Type of Tx/Rx is Solid-state TR modules (256)
- Pulse length range is 0.25µs to 8 µs
- System recovery time is < 0.5µs

3 Data Processing

The received signals are converted into quadrature base band signals using the down converter and quadrature detection. The demodulated quadrature signals, which represent the combination of signal plus noise are sampled at regular intervals. The Data processing steps includes pulse compression, coherent integration, spectral processing steps like clutter removal, incoherent integration etc.

The maximum range capability of the radar wind profiler is directly proportional to the square root of the average transmit power, which is the product of peak power and duty ratio (τ /T), where T is the inter-pulse period. The Profiler's Range Resolution is equal to $c\tau$ /2. The best range resolution is obtained with short pulse length but the profiler's height coverage will be minimum due to low average transmit power.

The time series complex data {(I_i, Q_i), i = 0, 1. . . N_{FFT} - 1} is subjected to FFT to obtain the complex Doppler spectrum {(X_i, Y_i), i = 0. . . N_{FFT} - 1} of the received echoes. I_i and Q_i are the in-phase and quadrature components in time series data, Xi and Yi are the real and imaginary components of the complex Doppler spectral data, and N_{FFT} is the number of time series points. Doppler spectra are usually 'incoherently averaged over a minute. The incoherent averaging procedure makes it easier to discriminate the signal from the noise, i.e., improves the detectability.

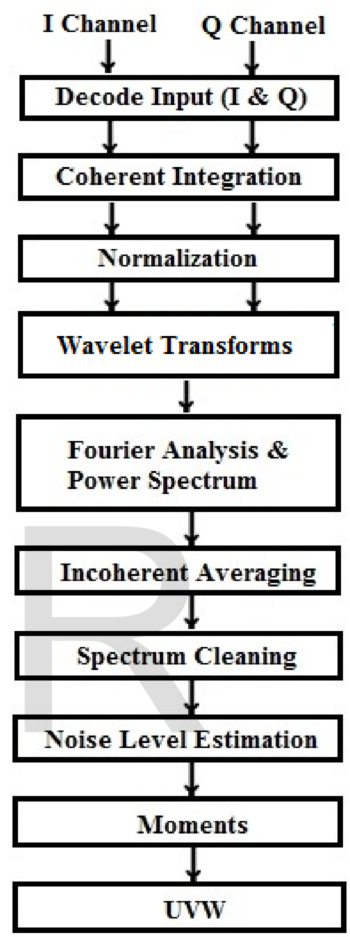

Fig 2: Data Processing steps for LAWP Radar

4 Methodology

4.1 Empirical Mode Decomposition

The Empirical Mode Decomposition (EMD) is one of method for analysing the non-linear and non-stationary signals. This method is used for analysing the multi component signals that breaks them down into a number of amplitude and frequency modulated zero-mean signals, termed Intrinsic Mode Functions (IMFs). EMD expresses the signal as an expansion of basis functions that are signal-dependent and are estimated via an iterative procedure called sifting Process. EMD adaptively decomposes a multi component signal $x(t)$ into a number L of the so-called IMFs $h^{(i)}(t),\ 1 \le i \le L$.

ISSN 2229-5518

$$x(t) = \sum_{i=1}^{L} h^{(i)}(t) + d(t) \qquad (1)$$

Where $d(t)$ is a reminder that is a non-zero-mean slowly varying function with only few extreme.

Each one of the IMFs, the ith one $h^{(i)}$, is estimated with the aid of an iterative process, called sifting, applied to the residual multi component signal

$$x^{(i)}(t) = \begin{cases} x(t) & i=1 \\ x(t) - \sum_{j=1}^{i-1} h(j)(t) & i \geq 2 \end{cases} \qquad (2)$$

The EMD context means that its subtraction from $x^{(i)}(t)$ will lead to a signal, which is actually the corresponding IMF is given by

$$h^{(i)}(t) = x^{(i)}(t) - m^{(i)}(t) \qquad (3)$$

EMD Processing Steps:
Given a non stationary signal $x(t)$, the EMD algorithm can be summarized into following steps:

Step (1): Finding the local maxima and minima: then connecting all maxima and minima of signal $x(t)$ using cubic spines to obtain the upper envelope $x_u(t)$ and lower envelope $x_l(t)$ respectively.
Step (2): Computing local mean value of data X(t),

$$m_1(t) = \frac{1}{2}(x_u(t) + x_l(t)) \qquad (4)$$

subtracting the mean value from signal $x(t)$ to get the difference:

$$h_1(t) = x(t) - m_1(t) \qquad (5)$$

Step (3): Regarding $h_1(t)$ as new data and repeating steps (1) and (2) for k times, value of $h_{1(k-1)}(t)$and $h_{1k}(t)$.

$$h_{1k}(t) = h_{1(k-1)}(t) x(t) - m_{1k}(t) \qquad (6)$$

It is terminated until the resulting data satisfies the two conditions of an IMF, defined as $c_1(t) = h_{1k}$ and the residual data

$$r_1(t) = x(t) - c_1(t) \qquad (7)$$

Step (4): Regarding $r_1(t)$ as new data and repeating steps (1), (2) and (3) until finding all the IMFs. The sifting procedure is terminated until the nth residue $r_n(t)$ becomes less than a predetermined small number or the residue becomes monotonic.
Step (5) Repeat steps 1 through 4 until the residual no longer contains any useful frequency information. The original signal is, of course, equal to the sum of its parts. If we have 'n' IMFs and a final residual $r_n(t)$. Finally the original signal $x(t)$ can be expressed as follows:

$$x(t) = \sum_{i=1}^{n} c_i + r_n \qquad (8)$$

4.2 Wavelet Transforms:

Wavelet is one of the method for analyse the non-linear and non-stationary signals. Wavelets tools are used for removing noise from a variety of signals (denoising). A signal in the time domain is described by a function f(t), where 't' is usually a moment in time series.
Wavelet decomposition of a signal y(t) is

$$y(t) = \sum_{s} a_{u0}(s)\, \phi_{u0,s}(t) + \sum_{u}\sum_{s} d_{us}(s)\, \psi_{u,s}(t) \qquad (9)$$

$$\phi_{u,s}(t) = 2^{u/2}\ \phi(2^u t - s) \qquad (10)$$

$$\psi_{u,s}(t) = 2^{u/2}\ \psi(2^u t - s), \qquad (u, s \in Z) \qquad (11)$$

u is the dilation parameter and s is the translation parameter. $\phi(t)$ and $\psi(t)$ are called scaling and wavelet functions respectively. a_{u0} and d_{us} are called wavelet coefficients.

Wavelet technique is one of the most important methods for removing noise and extracting signal from any data. Mallat defines a wavelet as a function of zero average,

$$\int_{-\infty}^{\infty} \psi(t) dt = 0 \qquad (12)$$

Which is dilated with scale parameter s, and translated by u:

$$\psi_{u,s}(t) = \frac{1}{\sqrt{s}} \psi\left(\frac{t-u}{s}\right) \qquad (13)$$

Wavelet analysis can often de-noise a signal without degradation. The term de-noising", describing various schemes which attempt to reject noise by thresholding in the wavelet domain. The aim of this study is to investigate the wavelet function that is optimized to identify and de-noise the radar signal.

Steps for denoising using Wavelets:

1. Selection of Wavelet
2. Selection of Threshold
3. Reconstruction

In this paper, Daubechies Wavelets has been used and it supports the orthonormal wavelet. The wavelet and scaling function for Daubechies exist up to order 20 and Db11 has been used to improve the SNR for the Lower Atmospheric signals. The properties of Db11 wavelet are asymmetric, orthogonal and bi-orthogonal. Wavelet thresholding (two types) is used for noise removal, in which the wavelet coefficients are threshold in order to remove their noise where first introduced by Donoho in 1993 [5]. One is Hard threshold is a "keep

ISSN 2229-5518

or kill" procedure and other is Soft thresholding shrinks coefficients above the threshold in absolute value. The soft thresholding provides smoother signals, when compared to hard thresholding.

5. Results

The South direction of 20th August, 2014 (sample data) is shown in Fig 3 and Fig 4.

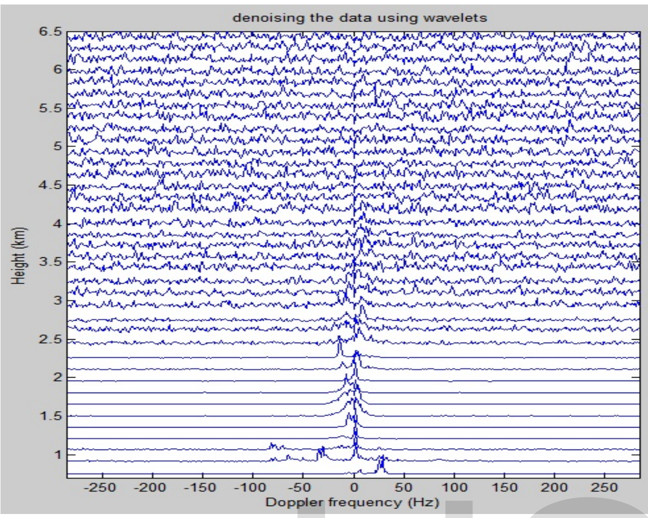

Fig 3: Befor denoising

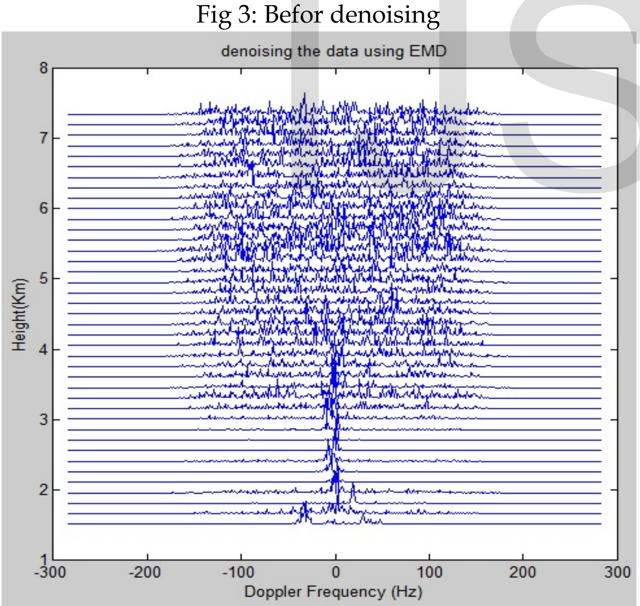

Fig 4: Denoising after denoising using EMD

Comparison of the signal to noise ratios for the North direction of 20th August, 2014 for the LAWP data before denoising and after denoising using Db11 Wavelet are shown in figure 8 and figure 9 respectively.

Table 1: Comparison of SNRs for the LAWP data

Date	By	SNR in dB			
	Using	**EAST**	**WEST**	**NORTH**	**SOUTH**
27 JULY 2015	DWT	9.2363	10.7126	9.6048	8.2008
	EMD	32.8379	31.1983	26.4907	26.8108
19 SEP 2014	DWT	10.2908	8.3036	8.4290	8.5762
	EMD	28.1173	26.555	26.4614	32.2331
20 AUG 2014	DWT	4.4542	6.3965	7.3864	10.3718
	EMD	24.6049	26.1658	24.1997	28.8948
31 MAY 2014	DWT	6.5599	4.0731	4.0123	6.7032
	EMD	26.5085	25.3236	24.5986	27.1046

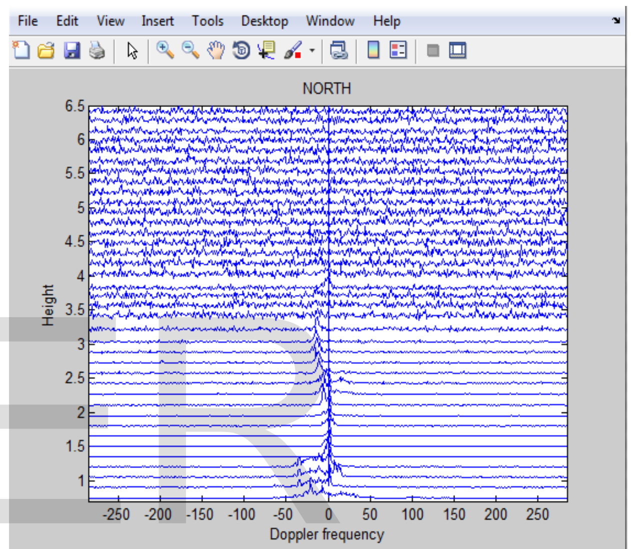

Fig 5: Before denoising

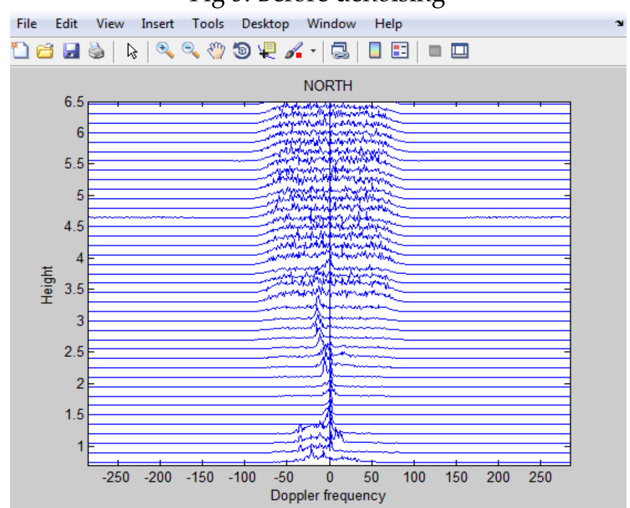

Fig 6: After denoising using Db11 Wavelets

Table 2: Comparison of SNR

	East	West	Zenith	North	South

Db7	19.503	18.827	19.171	19.289	19.022
Db8	20.126	19.319	19.734	19.675	19.461
Db9	19.384	28.468	19.217	18.751	18.755
Db10	20.248	19.575	20.214	19.789	10.682
Db11	**21.444**	**20.841**	**21.543**	**20.869**	**21.007**
Db12	20.799	19.891	20.687	20.092	20.221
Db13	20.736	19.920	20.706	20.082	20.063

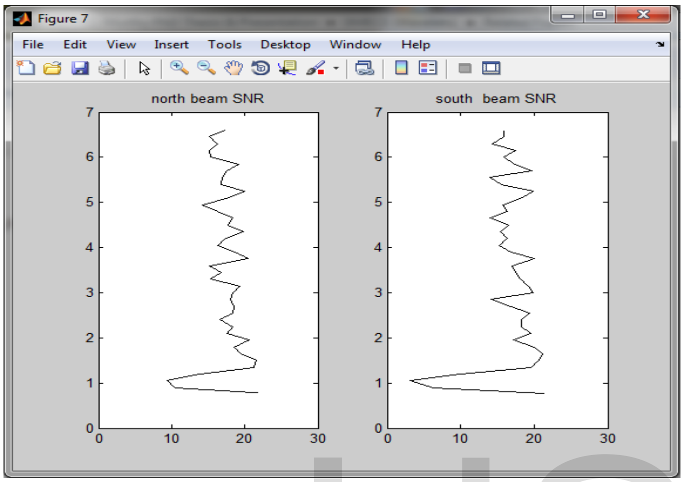

Fig 7: Beam SNR in North and South directions using Db11 Wavelet

6 Conclusion

Daubechies Wavelets serve as a tool for the task of signal denoising. The de-noising methods for LAWP signals have been improved by smoothing the signals. In this paper, we have discussed about the improvement of signal to noise ratio of LAWP Radar signals using EMD and Db11 Wavelet. The improvement is observed by comparing EMD denoised signal and Daubechies wavelet de-noised signal is 9 dB and 21 dB respectively. The improvement is observed by comparing these algorithms and improved the reliability of wind measurements. From the above discussion, it is concluded that an improvement of 21 dB is observed after de-noising.

7 End Sections

7.1 Acknowledgment

Prof. D. Jayaraman, Director, Smt. P. Yashoda, Scientist/Engineer - SD and P. Kamaraj, Scientist/Engineer - SD from NARL, Dept. of Space, Gadanki is gratefully acknowledged for supporting and providing the data.

7.2 References

[1] P. Srinivasulu, P. Yasodha, S.N. Reddy, S. Satyanarayana and A. Jayaraman, "Simplified Active Array L-Band Radar for Atmospheric Wind Profiling: Initial Results", *Journal of Atmospheric and Oceanic Technology*, Volume 28, 1436- 1447, November 2011. (http://journals.ametsoc.org/doi/pdf/10.1175/JTECH-D-11-00011.1)

[2] P. Srinivasulu, P. Yasodha, S.N. Reddy, P. Kamaraj, T.N. Rao, S. Satyanarayana, and A. Jayaraman, "1280 MHz Active Array Radar Wind Profiler for Lower Atmosphere: System Description and Data Validation", *Journal of Atmospheric and Oceanic Technology*, Volume 29, 1455-1470, October 2012. (http://journals.ametsoc.org/doi/abs/10.1175/JTECH-D-12-00030.1)

[3] Teter H. Hildebrand and R.S. Sekhon, "Objective Determination of The Noise Level In Doppler Spectra", *Journal of Applied Meteorology*, Vol-13, pp 808-811, 1974. (http://journals.ametsoc.org/doi/abs/10.1175/1520-0450(1974)013%3C0808%3AODOTNL%3E2.0.CO%3B2)

[4] Yannis Kopsinis, Stephen McLaughlin, "Development of EMD-Based Denoising Methods Inspired By Wavelet Thresholding", *IEEE Transactions on signal processing*, Vol. 57, No. 4, April 2009. (http://ieeexplore.ieee.org/document/4760240/)

[5] Daubechies I, "The Wavelet Transform, Time-Frequency Localization and Signal Analysis", *IEEE Transformation and Information Theory*, Vol. 36, pp. 961-1005. (http://ieeexplore.ieee.org/iel1/18/2073/00057199.pdf)

[6] Jordan, J.R., Lataitis, R.J., & Carter, D.A. "Removing Ground and Intermittent Clutter Contamination from Wind Profiler Signals Using Wavelet Transforms", *Journal of Atmospheric and Oceanic Technology*, 14, 1280-1297, 1997. (http://journals.ametsoc.org/doi/full/10.1175/1520-0426(1997)014%3C1280%3ARGAICC%3E2.0.CO%3B2)

[7] E. E. Clothiaux et al., "A first-guess feature-based algorithm for estimating wind speed in clear-air Doppler radar spectra," *Journal of Atmospheric and Oceanic Technology*,, vol. 11, pp. 888–908, 1994. (http://journals.ametsoc.org/doi/abs/10.1175/1520-0426(1994)011%3C0888%3AAFGFBA%3E2.0.CO%3B2)