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Lifting Wavelets with OGS for Doppler Profile Estimation

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ABSTRACT- This article discusses the second-generation wavelet transform concept and technique and its application to the noise removal problem of MST radar data. Located near Gadanki in Andhra Pradesh, India, the MST radar is collecting data on climate change. To obtain weather data, the signal collected by the radar needs to be analyzed, which usually requires power spectrum estimation. Most parametric and non-parametric methods cannot predict Doppler at an altitude above 14 KM, which makes to search for introduction of new denoising methods. More research is predominantly done on many denoising algorithms and tested with the simulated signal with various thresholds. It is observed that Lifting wavelets (LWT) with OGS is more effective in denoising the signals. Split, predict, and update are the three phases of lifting transform which on application of these steps reduces noise effectively. The LWT with OGS is applied to MST radar data and the research results shows that the noise level is reduced at higher altitudes and the signal-to-noise ratio is improved.

Keywords: MST RADAR Signal Processing, Doppler Estimation, Lifting Wavelets, Overlapping Group Shrinkage, Wind Speed.

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1. INTRODUCTION

For many years, radar has been used successfully to monitor atmospheric movements at various altitudes, from the ground to the ionosphere, hundreds of kilometers away. Atmospheric signal processing has attracted the attention of many researchers because of its new and useful way of extracting spectra looking for wind features that need to be predicted, such as zonal (u), meridian (v), and vertical (w) components. With the development of the Radar systems, some radar signal processing and detection has also been improved. A significant issue in the processing of radar signals is the recognition of radar targets when there is interference. Wavelet transform (WT) has been incorporated into signal processing in recent years. Since it not only captures the properties of the Fourier transform (FT), it becomes an important analytical tool in mathematics, signal processing and other disciplines, but also has good local properties of shortwave. Short time Fourier Transform (STFT). The application of wavelet analysis in radar systems has become a topic in education [1]. In [1] radar pulse edges were detected by wavelet transform. WT [2] calculates the delay and time changes for the radar plane. Finally, wavelet- based noise removal (WBD) is used for real-time detection of radar targets [3]. WBD is undoubtedly one of the most significant applications of WT in radar signal processing.

Multi band Discrete wavelets can also use in reducing the noise at higher altitudes [4] Using MST radar data backscattered by high altitude clouds, bad weather, and signal-to-noise ratio, this study develops a signal processing method based on a lifting wavelet with overlapped group shrinkage to estimate the above parameters. Compared to existing methods, where manually estimate Doppler fail at higher altitudes, the proposed method is self-consistent in determining wind speeds up to 20 km altitude. GPS sonde balloon measurement were used to verify the accuracy of the results.

2. DENOISING

Many research studies produce data that is affected by noise from the data collection process or the environment. Denoising or estimating signals of interest from noisy data is an important first step in the analysis of big datasets. Signals and images can be denoised in many ways. While their aesthetics are similar, there are slight differences in noise removal, blurring, smoothing and restoration. Blurring increases the sharpness of signal qualities by introducing noise, while noise removal seeks to eliminate all noise that is unrelated to the spectral composition of the noise. They efficiently remove high frequencies while keeping low frequencies. Restoration is a type of noise removal that balances blurring and smoothing to recover as much of the original signal as possible. Those that work with undetectable spatial effects such as mean, median and Gaussian smoothed signals [3].

For noise removal in the wavelet domain, the phrases wavelet thresholding, wavelet shrinkage, and nonlinear shrinkage are employed. [4] mainly pioneered noise reduction by thresholding in the wavelet domain. Small coefficients in the wavelet domain are often noisy, whereas large coefficients in the wavelet domain are signal dependent. Inverse Transformed with appropriate threshold or shrinkage, coefficients are used to obtain noise-free data [5].

The noise level should be measured for the threshold. [6] examined the estimation in the wavelet domain and presented the estimation of the maximum resolution The results are derived from the empirical wavelet coefficients. Since empirical wavelet coefficients are mostly noise, only the best values are measured. The noise level $\hat{\sigma}$ is calculated using the median absolute deviation given from *eq. (1).*

$$\hat{\sigma} = \frac{median\{P_m(n)|: n = 1,2 \ldots\ldots \frac{N}{2}\}}{0.6745} \quad (1)$$

where $P_m(n)$ are the fine-grained detail coefficients (output of high pass filter). There will be N/2 detail coefficients after the first step of filtering if we started with N sampling data [7]. The following is how the wavelet coefficients threshold is applied Let p indicate a single detail coefficient at level m, $\hat{p}$ as well as its modified form when the threshold is applied. $P^{\lambda}(.)$ denotes the thresholding function and π is the threshold. This controls how the data will be threshold and is shown below in *eq (2).*

$$\hat{p} = \hat{\sigma} \,.\, P^{\lambda}\left(\frac{p}{\hat{\sigma}}\right) \quad (2)$$

3. LITERATURE SURVEY

Sreenivasulu Reddy Thatiparthi et al. [8] introduced a Wavelet based denosing radar signal. It deliberately yields better results in estimating the wind parameters and can able to detect the wind speeds at higher altitudes. G.Chandraiah et al. [9] suggested the Eigen decomposition-based sub-space approaches, *i.e.*, the principle component based spectrum calculation utilizing the minimal variance spectral estimate method. It is used to process MST radar data in order to estimate the Doppler spectrum and to detect wind components using the Doppler. It is more prevalent at higher elevations.

C.Raju et al. [10] proposed a non-parametric and hyper parameter-free iterative adaptive approach (IAA) for power spectral density estimation was developed. For simulated data, the IAA approach gives precise amplitude and frequency estimates. When compared to previous methods, IAA provides exceptional results when estimating the power spectrum. G.Chandraiah et al. [11] proposed Multi-band wavelet transform which was used for denoising atmospheric radar signals, cleaning the Doppler spectrum, and detecting and estimating wind velocity characteristics such as zonal (U), meridional (V), and wind speed (W). The proposed algorithm's performance (Multi-Band Discrete Wavelet Transform) is assessed by comparing it to the DWT (Discrete Wavelet Transform). It generates better parameter wind speed measurements when the signal-to-noise ratio is low.

Suresh Babu Potladurty et al. [12] introduced a method for the effective spectral estimation of MST Radar signal called IAP. IAP is employed for MST radar data is used to determine the Doppler spectrum and wind velocity parameters are estimated using Doppler profiles. The derived MST radar observations utilizing IAP were compared to Global Positioning System (GPS) radiosonde data to validate the experimental results. Suresh Babu Potladurty et al. [13] developed a novel method of denoising the MST Radar signal. When compared to the Discrete wavelet transform and other earlier techniques, the Dual tree complex wavelet transform with OGS achieved improved SNR, Variance, and Correlation factor.

4. OBJECTIVES

1.To propose a method that denoises the radar signal.
2.To estimate the Power Spectrum, Doppler frequency, SNR.
3.To evaluate the wind parameter values, correlation factor.
4.To compare the evaluated parameters with existing Algorithms.

5. PROPOSED WORK

5.1 Lifting Wavelet Transform [14]

Let us assume the original signals l_j are divided into two parts: one low-frequency signal l_{j-1} and another high-frequency detail signal m_{j-1}. The three stages of the lifting scheme's transformation are split, forecast, and update.

5.1.1 The Split step

Two subsets that do not overlap l_{j-1} and m_{j-1} of the original signals l_j are created. The better the split effect, the higher the correlation between them. As indicated in *eq. (3)*, a signal sequence is often separated into odd and even sequences.

$$l_{j-1} = l[2n] \,,\, m_{j-1} = l[2n-1] \quad (3)$$

The split technique appears basic yet smart in terms of the lifting process. It serves as the foundation for the next two phases, which are to anticipate and update signals l_j based on their local similarity.

5.1.2 The predict step

We can predict m_{j-1} from l_{j-1} data similarity by employing a predict operator q that isn't affected by the dataset. The wavelet coefficients m(n), represent the resulting difference, and they show how similar the two data sequences are. As indicated in *eq. (3)*, a signal sequence is often separated into odd and even sequences. The following is a summary of the predict process defined in *eq. (4).*

$$m_{j-1} = l[\,2n+1\,] - q(\,l_{j-1}) = m_{j-1} - q(\,l_{j-1}) \quad (4)$$

5.1.3 The update step

The coefficient subset created l_{j-1} from the preceding two phases differs from the original dataset in a few ways. As a result, the update step is required. As a result, the upgrading procedure is required. We employ the U update operator to generate a better subset $l(n)$ that retains some of the original dataset's properties as indicated in *eq. (5).*

$$l_{j-1} = l[2n] + u(m_{j-1}) = \,l_{j-1} + q(\,m_{j-1}) \quad (5)$$

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The three steps stated above comprise a lifting strategy. We may obtain the approximation signals l_{j-n} and the high-frequency detail signals m_{j-n} by lifting repeatedly. After n decomposition cycles, the wavelet transform of the original data may be represented by $\{l_{j-n}, m_{j-n}, m_{j-n+1}, m_{j-1}\}$. Each wavelet may be divided into a number of different lifting methods. In general, the predict step seeks to eliminate low-order polynomial components while keeping high-order detail signals. The purpose of the update phase at coarse sizes is to maintain the low-order polynomial elements. By changing the operation orders and signs, we may easily achieve the following reconstruction *eq. (6)*:

$$l_{j-1} = l_{j-1} - q\left(m_{j-1}\right) \text{ and } m_{j-1} = m_{j-1} + q\left(s_{j-1}\right) \quad (6)$$

The aforementioned technique may be used to do the whole lifting wavelet decomposition and reconstruction, as specified in below *figure 1*.

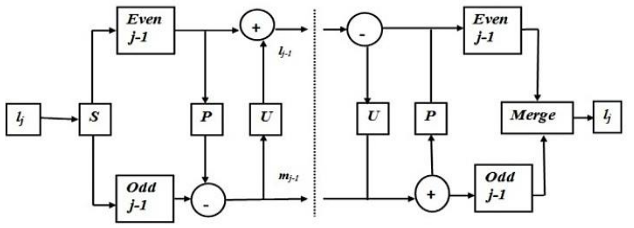

Figure 1: LWT Decomposition and Reconstruction

6. METHODOLOGY FOR PROPOSED WORK

Denoising noisy signals using wavelet shrinkage x(n) to recover y(n) as an approximation to the original signal s(n) is shown as a four-step approach [8], with m representing decomposition levels, W representing forward LWT, and W^{-1} representing inverse LWT.

- $w_m = W(x)$, m=1 to M
- λ_m = Level adaptive threshold selection (w_m)
- $z_m = OGS(w_m, \lambda_m)$
- $y = W^{-1}(z_m)$

The *figure 2* represents the proposed methodology flow diagram used to estimate the Doppler profile, SNR Evaluation and computation of wind speed components.

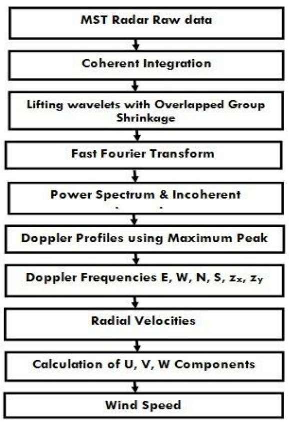

Figure 2: Flow Diagram of Proposed Framework

7. RESULTS AND DISCUSSION

We used data obtained from the troposphere and lower troposphere while operating the MST radar at Gadanki, India, to apply wavelet analysis to radar backscattered signals. We utilized raw data collected on February 9th, 2015 to evaluate the proposed approach (PALG) and compare it to the previous method EALG (CWT with OGS) [9]. *Figure 3(a)* shows the raw data spectrum of the east beam without denoising. The Doppler effect may be seen up to a height of 11 km, after which air noise dominates the spectral component. *Figure 3(b)* depicts the EALG-based anticipated Doppler profile for the aforementioned data. Because of the low noise level, the EALG can detect Doppler up to 11 kilometers away. As noise increases over 11 km, the accuracy of EALG's Doppler calculation is in doubtful situation, as detailed in the sections below. Spectrum is generated after denoising radar data with a wavelet method to mitigate the influence of noise at high altitudes. *Figure 4(a)* shows the usual data spectra or Doppler profile prior to doing spectral cleansing and after denoising of the East Beam. The PALG (LWT with OGS) is applied to the data from all beams, and the Doppler for all beams is determined. *Figure 4(a)* depicts the East beam's Doppler Profile after adaptive window denoising. *Figure 4(b)* depicts the Doppler profile obtained after investigating radar data with the PALG. In the presence of air noise, the Doppler effect can be received at higher elevations, as demonstrated in bin-wise denoising is used rather than single denoising for the complete frame of information to reduce the opportunity of the desired peak allowance and improve signal detectability. The EALG, PALG, and GPS Sonde were used to determine the Zonal (*u*), wind speed components, and Meridional (*v*) [11]. Wind Parameters can be evaluated using the following Equations.

After estimate of Doppler frequency from Doppler spectrum, the Doppler velocity can be calculated by using *eq. (7)*

$$V_d = \frac{c * f_d}{2 * f_c} = \frac{f_d * \lambda}{2} \quad (7)$$

Where V_d - Doppler Velocity (m/s)
f_c - Operating Frequency of MST Radar (53 MHz)
f_d - Doppler Frequency
C – Velocity of Light

Wind velocity components can be determined by using

Velocity components as in *eq. (8)*

$$\begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix} = \begin{bmatrix} 0.603 & 0 & 0 \\ 0 & 0.603 & 0 \\ 0 & 0 & 0.603 \end{bmatrix}^{-1} * \begin{bmatrix} 0.736(v_E - v_W) \\ 0.736(v_N - v_S) \\ 0.736(v_{ZX} - v_{ZY}) \end{bmatrix} \quad (8)$$

Where v_x, v_y and v_z are Zonal (*U*), Meridonal (*V*) and Vertical components (*W*). Wind Speed was evaluated as shown in *eq. (9)*

$$W = \sqrt{v_x^2 + v_y^2} \quad (9)$$

It's also obvious that the PALG-predicted *u*, *v*, and wind speed components are more closely matched with the patterns provided by the GPS Sonde. As illustrated in *figure 5*, the suggested technique produces self-consistent profiles. When compared to previous algorithm, the PALG allows for substantially more in accuracy in Doppler tracking.

Figure 6 shows the SNR estimated using Periodogram and PALG (LWT with OGS) of East-Beam and West-Beam for raw data gathered on 09-04-2015.

It was observed from the *figure 6* that PALG produces an SNR which is more predominantly positive compared to periodogram both for East beam and West beam.

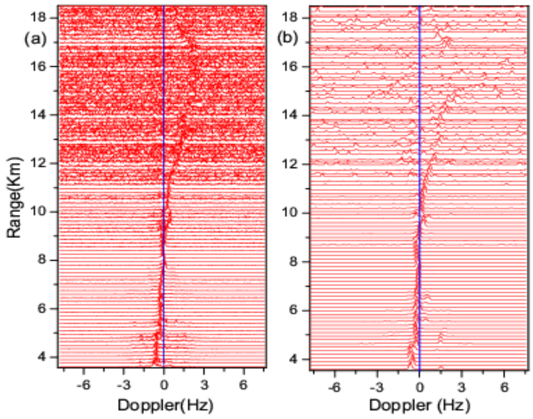

Figure 3: Typical East beam spectrum, (a) Before spectral cleaning, (b) After spectral cleaning with EALG

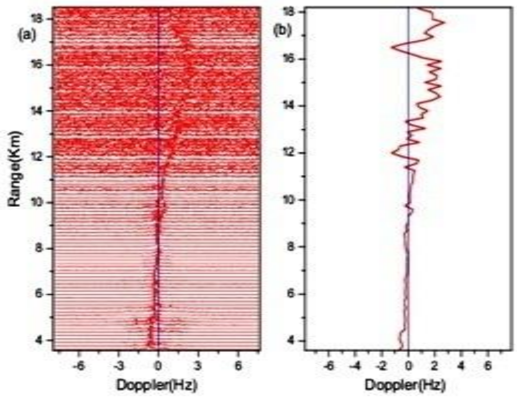

Figure 4: (a) Prior to doing spectral cleansing (b) After Denoising

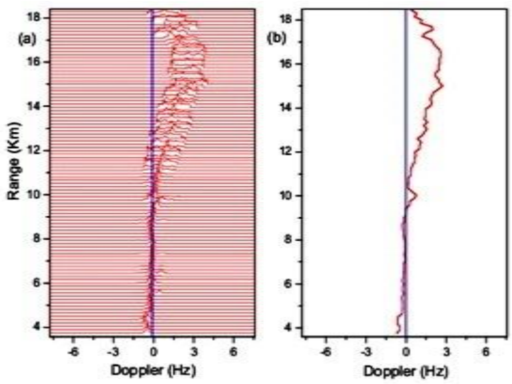

Figure 5: Typical East beam spectrum, (a) Adaptive window on a denoised spectrum, (b) Doppler Profile

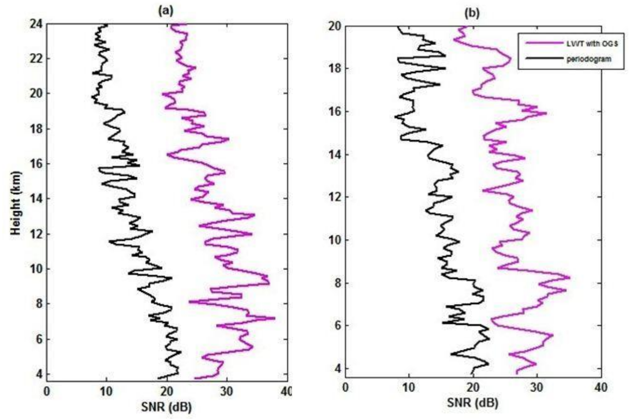

Figure 6: SNR estimated using Periodogram and LWT with OGS for raw-data on 09-04-2015. (a) East-beam (b) West-beam

Figure 7(a), (b) and (c) shows the Comparison of velocity components of MST Radar raw-data on 09-04-2015 using LWT with OGS, ADP, GPS.

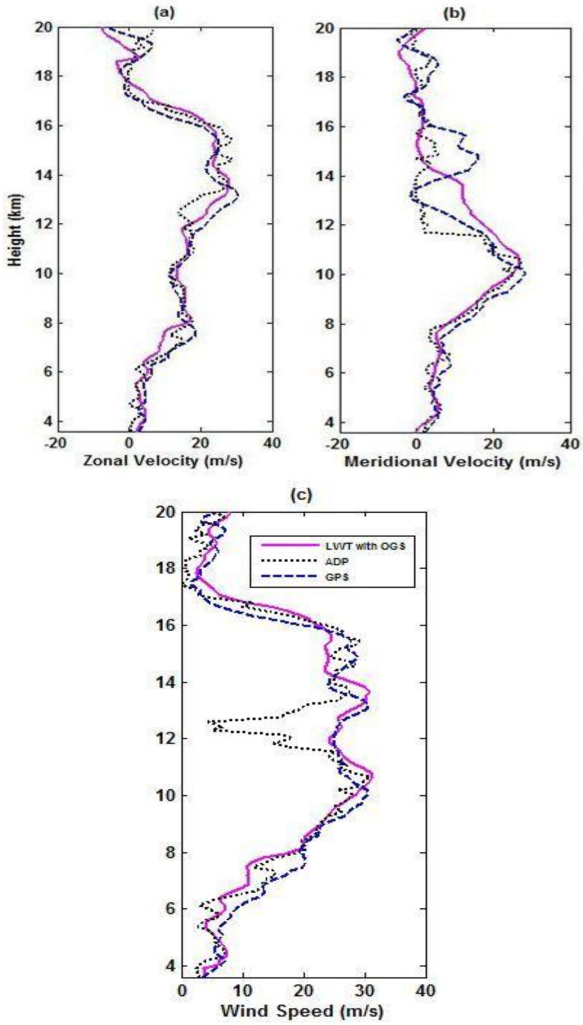

Figure 7: Comparison of velocity components (a) Zonal, (b) Meridional (c) Wind-speed for raw-data on 09-04-2015 using LWT with OGS, ADP, GPS.

Figure 8 shows the Comparison of wind speed using LWT with OGS, CWT with OGS, ADP, GPS for radar raw-data gathered on 09-04-2015.

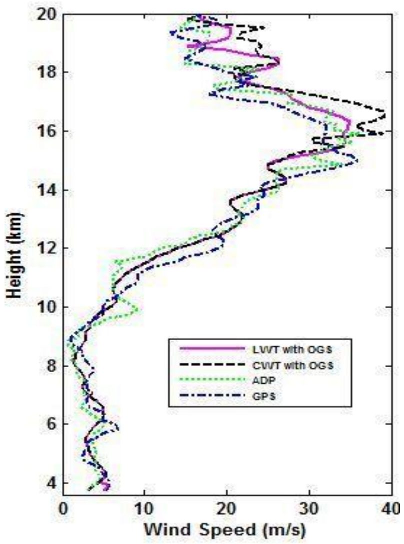

Figure 8: Comparison of wind-speed using LWT with OGS, CWT with OGS, ADP, GPS for radar raw-data gathered on 09-04-2015

Figure 9 shows the Correlation plot using LWT with OGS & GPS for raw-data during 9 to 11 Feb, 2015.

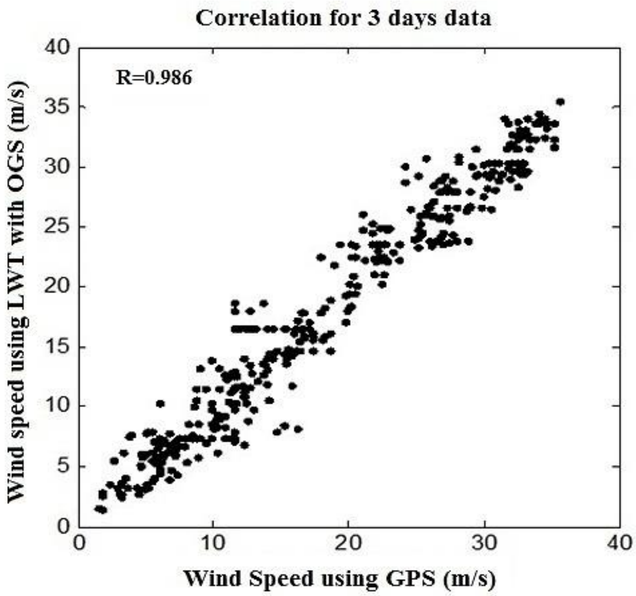

Figure 9: Correlation plot between wind speed using LWT with OGS and GPS for data during 9 to 11 Feb, 2015

By using the PALG, the correlation of 0.986 is obtained for 3 days data as specified in the *figure 9*.

The PALG is compared with the Periodogram, Discrete Wavelets with OGS and Complex Wavelets with OGS in terms of the parameter SNR (Average SNR) for all the beams for the data on July 8, 2014 and found the SNR is outperformed in PALG which is shown in the *table 1*.

Table 1: Comparison of Average SNR (dB)

Algorithm	East	West	Zenith -Y	Zenith -X	South	North
Periodogram	13.49	14.01	14.22	13.85	14.19	13.92
DWT with OGS	19.16	18.24	18.35	18.98	20.25	18.17
CWT with OGS	21.34	20.25	23.18	21.95	22.16	21.65
LWT with OGS	28.56	27.26	25.89	24.78	25.69	23.67

8. CONCLUSION

The proposed technique is utilized for processing MST RADAR data for Doppler estimation, SNR computation & wind parameter estimation. Overlapping group shrinkage (OGS), which is particularly effective in processing the sparse data because unlike other wavelets, OGS have the importance of grouping the similar coefficients and applying the shrinkage to the coefficients and making then non-zero. So, the PALG gave better results when compared to other algorithms in terms of SNR, Doppler Profile and Wind Speed Calculations.

The PALG achieves a correlation factor of 0.986, which is higher than any other thresholding technique.

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