Spectral Estimation of MST Radar Data using IAP

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Abstract:-The Indian Mesosphere-Stratosphere-Troposphere (MST) radar is located at NARL, Gadanki, near to Tirupati. It is operating for providing dynamic information regarding atmospheric moments. To acquire information about the wind speed, the data received from the MST radar, which mostly involves the evaluation of Doppler power spectrum. Standard power spectral analysis of unequal sampled data generates undesirable side lobe power levels and cannot be controlled through a periodogram and also window based periodogram. In this work, we proposed Iterative Adaptive periodogram (IAP) technique which is able to achieve desired side lobe levels, while computing the spectrum. Finally, IAP is applied to the MST radar signal to find the Doppler spectrum and thus, in turn, estimate the wind velocity parameters by using Doppler profiles. For the validation of experimental results, the obtained MST radar results using IAP have been compared by the Global Positioning System (GPS) radiosonde balloon measurements

Keywords: *Estimation of Doppler spectrum, periodogram, Iterative Adaptive periodogram, MST Radar and GPS radiosonde.*

I. INTRODUCTION

Radar can be working for the detection and exact location of the remote targets. The Doppler radars can be used for remote sensing applications. To study and analyze the behavior of the atmosphere, the Mesosphere-Stratosphere-Troposphere (MST) Radar is situated at The National Atmospheric Research Laboratory (NARL), Gadanki. The Indian MST Doppler Radar is in commission at a frequency of 53 MHz based on Doppler principle. It provides the atmospheric data starting from an altitude of 3.6 Km with a height resolution of 150 m. The atmospheric radars are clear air radar and they can work typically in VHF (30 – 300MHz) and UHF (300 – 3 GHz) frequency bands. MST radar produces information on atmospheric winds. Doppler profiles can be acquired from the radar echoes and further the Doppler frequency profiles can be used to work out the radial velocities.

Currently the NARL processing the radar data by using the "Atmospheric Data Processor" (ADP) [1]. Naturally Non-uniformly sampled of data has advantages in a number of fields including biomedical signal processing, astronomy and Doppler radar signal processing. In cardiac signal processing, heart beats are obviously happening in Non-uniformly sampling actions used for heart beat rate variability analysis [2]. In astronomy, data observations recorded in irregular time periods due to imperfect atmospheric conditions, and spectrum estimation of such unequally spaced data is often discussed [3]. In radar applications, Non-uniformly PRF gives a number of advantages are discussed [4]. In this paper, main focus is on spectrum estimation of Non-uniformly sampling of radar time series complex data. Doppler estimation processing involves spectral analysis of slow time samples is a basic step in Doppler radar signal processing to cut off clutters and detect targets based on their movement. So there is a scope to develop efficient spectral estimation algorithms to estimate Doppler and wind parameters using Non-uniformly spectral estimation method.

II. PROPOSED ALGORITHM

DFT

The discrete Fourier transform (DFT) of a signal $x(t_n)$ sampled at $n=1,\cdots N$ is given by

$$X(f)=\sum_{n=1}^{N} x(t_n)e^{-j2\pi f t_n} \quad (1)$$

This formula is valid regardless of whether $x(\cdot)$ is sampled at uniformly or Non-uniformly. For time-limited signals, the summing up in (1) habitually results in undesirable in the spectrum $X(f)$, hence a window function can be typically applied to reduce the side lobe levels. The choice of a window function $w(\cdot)$ determined by the clutter power level achieves required side lobe level suppression for equally sampled signals. The corresponding spectrum is given as

$$X_w(f) = \sum_{n=1}^{N} x(t_n) w(t_n) e^{-j2\pi f t_n} \quad (2)$$

Even though $X_w(f)$ can attain satisfactory side lobe levels in the evenly sampled case at $t_n = nT$ where T is the identical sampling time period, for the un evenly sampled case it still fails to reach the most wanted side lobe suppression.

IAP

An Iterative Adaptive periodogram (IAP) technique is presented by stoica [7]. In this proposed technique, a weighted least-squares spectrum is estimated iteratively. In each and every iteration step, weighting coefficients are updated based on previous spectrum estimation. It is data dependant one, hence it is an adaptive method. Let $f_k, k = 1 \cdots K$, be the frequency points where the spectrum is computed. The complex sinusoid on f_k sampled at t_n is given by

$$a_k = \left[e^{j2\pi f_k t_1}, \cdots, e^{j2\pi f_k t_n} \right]^T \quad (3)$$

Then, the basis matrix of interest A is given by [8]

$$A = \left[a_1 \cdots a_k \right] \quad (4)$$

The vector of received signal $x(t_n)$ is denoted by s. The power spectrum estimation of vector s in the i^{th} iteration is given by

$$S^i = \left[A^H (R^{i-1})^{-1} A \right]^{-1} \left[A^H (R^{i-1})^{-1} s \right] \quad (5)$$

where R^{i-1} denotes the weighting matrix and it can be obtained from the past iteration

$$R^i = A\,\mathrm{diag}\left(\left| S_k^i \right|^2 \right) A^H \quad (6)$$

For the first iteration, the weighting matrix is set to an identity matrix, i.e. $R^0 = I_N$ and the proposed algorithm is terminated from the iteration loop when

$$\left\| S^{i+1} - S^i \right\|_2 < 10^{-3}.$$

III. RESULTS

NARL issues the data from MST radar as bins, beams and scan cycles. Each bin contains 512 complex-time series samples. The Doppler spectrum is estimated using the PER and IAP for each bin of data. Further, the Doppler frequency is computed through the maximum peak detection technique from the Doppler spectrum. The same process would repeat for all the bins as well as all the beams. After obtaining six beams of Doppler profiles, the Doppler (radial) velocities (v_E, v_W, v_N, v_S, v_{ZX} and v_{ZY}) are calculated by multiplying each of the frequency component with $c/2f_c$. Where c and f_c are light velocity ($3\text{x}10^8$ m/s) and the radar operating frequency (53MHz) respectively. The atmospheric wind speed [9] is computed by using radial velocities of 6 beam directions as follows:

$$\begin{bmatrix} v_X \\ v_y \\ v_Z \end{bmatrix} \begin{matrix} 0.603 & 0 & 0 \\ 0 & 0.603 & 0 \\ 0 & 0 & 0.603 \end{matrix} * \begin{bmatrix} 0.1736(v_E - v_W) \\ 0.1736(v_N - v_S) \\ 0.1736(v_{ZX} - v_{ZY}) \end{bmatrix} \quad (7)$$

where $\boldsymbol{v}_x$, $\boldsymbol{v}_y$ and $\boldsymbol{v}_z$ are the zonal, meridional, and vertical wind components respectively. The wind speed is computed as

$$W = \left(v_x^{\,2} + v_y^2 \right)^{1/2} \quad (8)$$

The signal-to-noise ratio is calculated for the east beam of MST radar data obtained on Feb 13th,2015 using both proposed (IAP) and existing (PER) algorithms is exposed in figure 1.From the figure 1,it is observed that, the IAP is performing improved SNR than PER technique at higher range bins. The IAP is applied to an aforementioned MST data for computing the Doppler profiles for the each of the 6 beam directions (E, W, N, S, Z_X and Z_Y). In Figure2, we present the east beam Doppler frequency profile of the MST data (a) Doppler spectrum without processing and (b) Doppler spectrum after processing (c) Doppler profile using IAP.

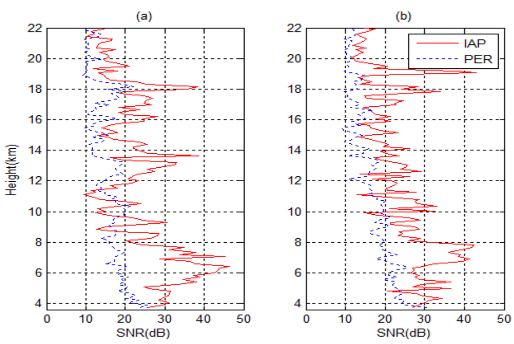

Figure1. *SNR estimated through periodogram (PER) and IAP for (a) East and (b) West beams of Feb 13th, 2015 radar data.*

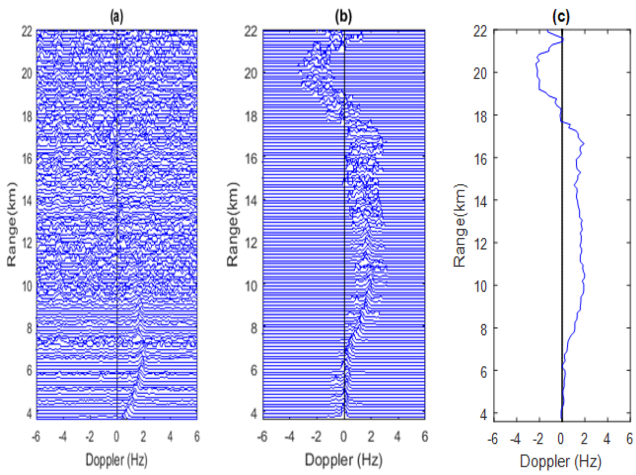

Figure 2. *(a) Typical Spectra for the east beam of radar data received on Feb 13th, 2015 (b) Spectra using IAP and (c) Doppler Profile.*

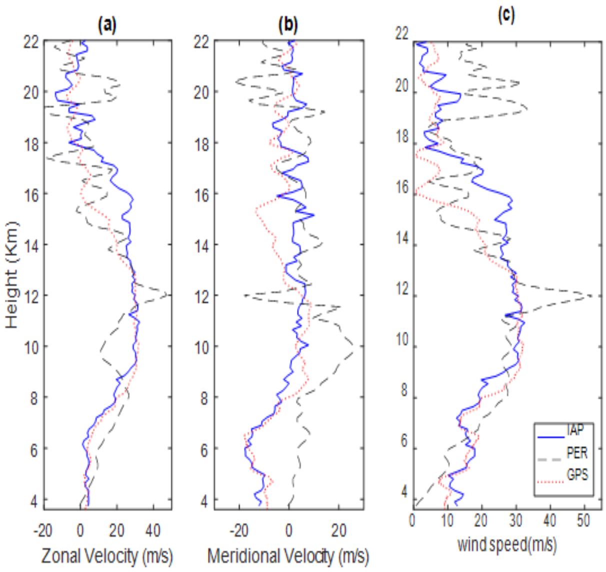

Figure 3*. Wind Speed Comparison profiles for the radar data on 13th February, 2015 using PER, IAP and GPS data.*

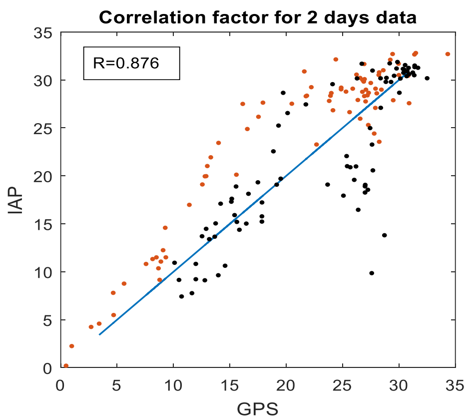

Figure 4*. Correlation plot between PER, IAP and GPS*

The Zonal (U), meridional (V) and wind speed (W) components are determined [10] for the radar data Feb 13th, 2015 and shown in figure 3. From the figure 3, it is identified that the wind velocities are obtained using PER is not follows as with the GPS. Whereas in IAP algorithm, the wind speed components are very much approached to GPS data. The correlation plot for the wind speeds between IAP and the GPS is revealed in figure 4. To test the consistency of the proposed algorithm, the correlation factor is computed for the aforementioned data. Correlation coefficients using IAP and PER algorithms is about 0.876 and 0.847 respectively. In view of relationship factor examination, the IAP has higher than PER.

IV CONCLUSION

This paper proposes a novel method, Iterative Adaptive periodogram named as IAP. The IAP achieves good Doppler resolution and clutter separation in low SNR conditions. However, this technique is useful in Doppler estimation processing of Non-uniformly time series radar data. It is applied to MST radar data acquired from NARL. When tested on radar data, it is found to produce superior results than the existing methods even in high contamination of noise in the radar signal. The IAP is a self-consistent in detecting the wind speed up to a height of 22 km, except at a height range of 14 km to 17 km. Significant improvement in estimation of Signal-to-Noise Ratio (SNR) is achieved by using IAP. The obtained radar results using IAP and PER for the data on 13th February, 2015 are validated with the GPS balloon measurements. The correlation factor between wind speed obtained using IAP and GPS is presented for the data collected on 10th February, and 13th February 2015 which attained the correlation coefficient of 0.876.

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