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Automated Algorithm for Accurate Doppler Profile Detection of MST Radar Signals Considering Removal of Interference

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Abstract**:** ***Identifying the accurate radar echo returns from the MST (Mesosphere-Stratosphere–Troposphere) region poses serious challenges, as the radar echo signals are of very low amplitude and hidden in noise. The process of extraction of the relevant signal information becomes intricate when the spectra sometimes are infected with interference signals of non-atmospheric origin. An automated algorithm is suggested for eliminating the interference bands in the Doppler spectra of MST radar signals. The process of removal of interference and de-noising of the radar echoes using soft thresholding techniques was achieved simultaneously. The algorithm was practically applied to interference contaminated MST radar data taken from National Atmospheric Research Laboratory (NARL), Gadanki, Tirupati and studied for removal of interference bands. It was found that the projected algorithm effectively removes multiple interference bands and also improves signal detectability. The power and Doppler values (moments) are estimated using FFT and HHT (Hilbert Huang Transform) and median Doppler is plotted on Doppler power spectrum and compared.***

Index Terms**:** ***MST Radar, Doppler Power spectrum, FFT, Interference, HHT.***

I. INTRODUCTION

Radar echoes received are very weak in nature and hence processing them and further analysis, espectially from MST (Mesosphere-Stratosphere–Troposphere) region is a hectic and difficult challenge to exhaustive signal processing techniques particularly at elevated heights beyond 15 kilometers, as the reflected signals are too feeble, hidden in noise. In addition, the Doppler spectrum is infected with the interference signals which are non-atmospheric origin, generated within the system due to various reasons such as arcing of high power devices. Proper recognition of intrusion and backscattered signals is the chief concern. An automated algorithm is proposed for eliminating the intervention bands (if present) in the Doppler spectra of the radar reflected signals. The process of removal of interference (if present) and de-noising of the radar echoes using soft thresholding techniques [14] was achieved simultaneously. This method uses a simple technique that identifies the interference signals with specific characteristics. Interference-frequency identification is observed in power spectral domain. This algorithm helps in detection and removal of the interference bands without manual intervention. The proposed algorithm is functional and is applied to time-series raw radar data obtained from the MST region in close proximity to Gadanki, Tirupati. The developed algorithm was tested for all the six beams viz. east, west, north, south , zenith'X and zenith'Y up to 25Km of 04th May 2012 data that is contaminated with interference .

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II. INTERFERENCE

The most common interference patterns observed in MST radar backscattered spectra are Zero-band, Rolling interference and U or V band interference. While rolling interference and zero band occurs at the equivalent Doppler frequency in each of the range bins of the spectra, the U/V band interference appears in U/V form on either sides of zero Doppler points when observed, on the spectral plot. In few instances, data sets are observed to be having both the above mentioned interference echoes and or multiple interference bands [13]. They have to be removed from the Doppler spectra before estimating the radar parameters. If the interference bands are observed far away from the atmospheric echo, complete removal of interference may not affect the signal. However, if the interference band coincides with the atmospheric echo, the removal of interference literally indicates the removal of atmospheric echo as well. Therefore, we need to understand the characteristics of interference bands in the radar spectra. This enables us in removing the interference from the radar spectra without eliminating the signal through an automated algorithm.

III. INTERFERENCE DETECTION AND REMOVAL ALGORITHM

Constant frequency bands will appear in the power spectrum due to the interference generated in the system or due to extraneous signal.

Interference frequency has unique characteristics with definite and nearly constant amplitude. Hence they appear at identical frequency in various range gates. Zero band and rolling intervention is visible at the identical Doppler frequency in each and every range gate. This phenomenon is used to recognize them in the spectra. But in case of interference generated by system, many frequencies are observed, and they spread across partially in few range gates. This disables the detection and makes it complicated with the usual technique. Interference-frequency identification is observed in the power spectral domain. The time-series radar data that is received is initially allowed for power-spectrum calculation using FFT (Fast Fourier Transform) and Hilbert Huang Transform (HHT) [5-7][16]. Mean-noise-level is estimated using the fundamental threshold value for the recognition of interference signals that are similar in nature from every range gate. Similar procedure is continued for each and every range gate and thus the Doppler frequency is identified beyond the set threshold value. For this, first we identified the noise floor at each altitude by using method proposed by Hildebrand and Sekhon [1]. The noise is further subtracted from all the spectral points for further processing. The three lower order moments viz. total power, mean Doppler and Doppler width are estimated using equations given by Woodman [2]. The resulting spectral points will have both positive and negative values. Negative values and fewer contiguous positive values (<3) are generally associated with noise and therefore are neglected. The interference, clutter (if any present), generally will have large number (> 5) of positive contiguous values. The shift in doppler is observed as spectral peaks at each height is examined to recognize and spot the interference. If one of those peaks (spectral) becomes visible at the same position of doppler in all the range bins, then it is well thought-out as interference. This helps us to segregate the signal that is erroneously chosen as interference. Then those values will be made equal to the noise floor so as to remove the interference.

A. *Steps to be followed to perform this Algorithm Using FFT*

Convert the time series radar raw signals into spectral signals using FFT by the following process:

i. Remove the DC level using 3 point running average method.
ii. Computation/ estimation of the corresponding mean noise level for every range bin by using Hildebrand Sekhon [1] Method.
iii. After Step 2, take away the mean noise level for each and every range bin and plot the corresponding stacked Doppler spectrum [3,4]
iv. Negative values of spectral points and fewer contiguous positive values (<3) are neglected.
v. The positive contiguous values (> 5) are made equal to the noise floor as they are due to interference (constant amplitude present in all range bins at same Doppler frequency.
vi. Plot the Median Doppler plots after interference removal.

B. *Steps to be followed to perform this Algorithm Using HHT*

Convert the time series raw signal into spectral signal using HHT [5-6]. The following are the processing steps:

i. Calculate the IMFs (Intrinsic Mode Function)[8,9] by using Empirical Mode Decomposition method for each and every range bin [10-12].
ii. Application of Hilbert Transform on every IMF for all the range bins.
iii. Apply the method of Soft Thresholding using denoising [14] following the steps mentioned below.
   a. Estimation of the level of noise '$\tilde{\sigma}_j$' in the IMF as proposed by Donoho and Johnstone [15] by calculating the median values of corresponding IMFs.
   b. Calculation of accurate value by comparing with the universal value of threshold (τ_j) for reference [15].
   c. If the estimated value of IMF is higher than or equivalent to τ_j, the IMF will be subtracted from τ_j, else if it is lesser than τ_j then it is made as zero and further if it is lesser/lower than or equivalent to $-\tau_j$, then the corresponding IMF will be incremented by τ_j. This process is applied on each and every range bin.
iv. Rebuild the waveform signal by accumulation all those of IMFs for each and individual range bin.
v. 3-Point running average method was applied on the signals in each range bin.
vi. Computation/ estimation of the corresponding noise level (mean) for each range bin by using Hildebrand method [1].
vii. Subtract the estimated noise level (mean) for each of the range bin and plot the corresponding the stacked doppler-spectrum.
viii. Negative values of spectral points and fewer contiguous positive values (<3) are neglected.
ix. The positive contiguous values (> 5) are made equal to the noise floor as they are due to interference.
x. Plot the Median Doppler plots after interference removal.

IV. RESULTS AND DISCUSSION

This proposed technique of algorithm can be applicable to different time series data for with and without interference for testing the efficacy. In particular, interference contaminated MST radar data of 04th May 2012 was collected from NARL Gadanki, Tirupati and the algorithm was applied for all the six beams up to 25Km. Results of West, Z'X and South beam are presented in the results.

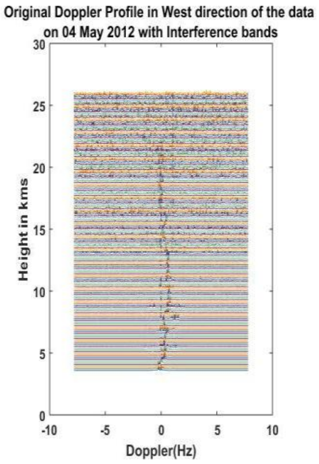


Fig.1a

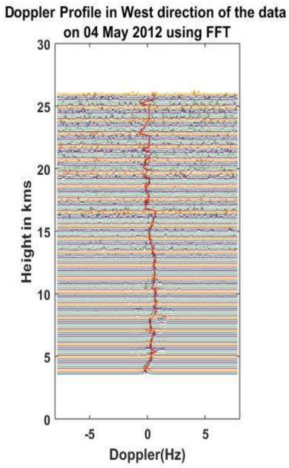


Fig.1b

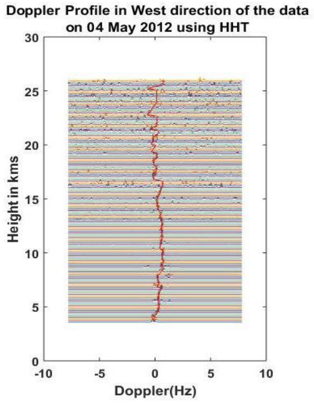


Fig.1c

Fig.1a. Actual Doppler Profile in West direction of the data of 04thMay 2012

Fig.1b.Median Doppler profile in West direction of the data of 04th May 2012 using FFT

Fig.1c. Median Doppler profile in West direction of the data of 04th May 2012 using HHT

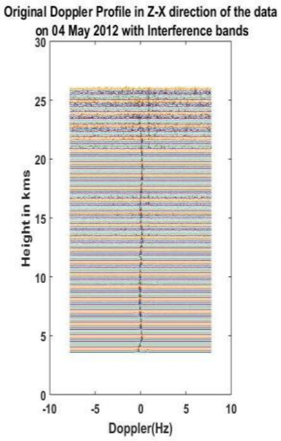


Fig.2a

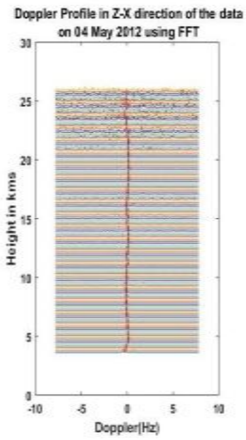


Fig.2b

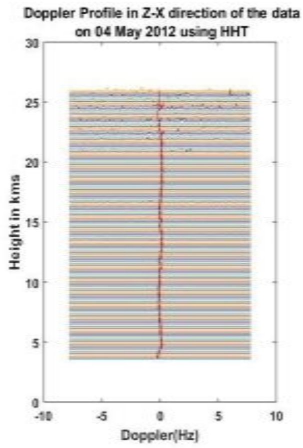


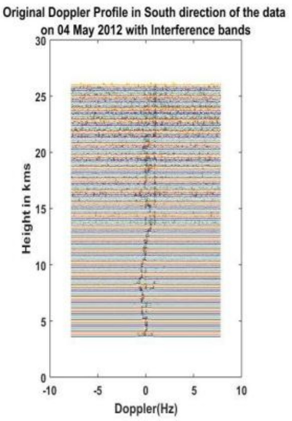
Fig.2c

Fig.2a. Original Doppler Profile in Z'X direction of the data of 04thMay 2012

Fig.2b. Median Doppler profile in Z'X direction of the data of 04th May 2012 using FFT

Fig.2c. MedianDoppler profile in Z'X direction of the data of 04th May 2012 using HHT

Figure 1a. corresponds to the doppler spectrum of 04th May 2012 in west direction contaminated with interference bands. Figures (1b) and (1c) are the Doppler spectrum after removing interference bands using FFT and HHT. Figures (2a), (2b) and (2c) are the corresponding Doppler spectrum of 04th May 2012 in Z'X direction with interference bands and after removing interference bands using FFT and HHT. Similarly, Figures (3a),(3b) and (3c) corresponds to south beam. In Figure (1a) shows the two obstruction bands that could be observed from the spectra at around 1Hz and -0.05Hz in west direction beam and extend from 13 km to 25 km and 5km to 22km respectively. Figure (2a) has one interference band at around 1 Hz extending from 13km to 25km. Figure (3a) also has two interference bands at around 1Hz and -0.05 Hz extending from 13km to 25km and 6km to 25km respectively. It can be observed that interferences have varied characteristics and are present throughout the same Doppler points in the range gates. In some cases the interference is not visible in the lower range gates because in real scenario the atmospheric signals are very much stronger than that of interference signals. It is evident from the results that the interference bands can be effectively eliminates from the power range and the stacked Doppler profile is clearly visible after HHT process has been applied. The West beam and South beams demonstrates the even multiple interference bands were also removed effectively and also improves the signal detectability.



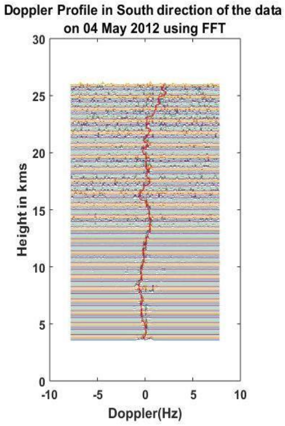


Fig.3a **Fig.3b**

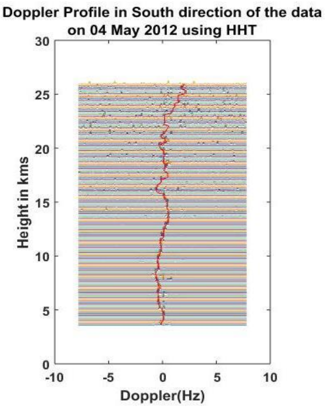


Fig.3c

Fig.3a. Original Doppler Profile in South direction of the data of 04th May 2012.
Fig.3b.MedianDoppler profile in South direction of data of 04th May 2012 using FFT.
Fig.3c.Median Doppler Profile of South direction data, 04th May 2012 (HHT)

V. CONCLUSION

An Automated Interference recognition and removal algorithm is developed and fruitfully tested on the MST radar signals up to an altitude of 25 km. It is also evident from the moment's evaluation that by eliminating the interference signal bands, the required signals at elevated heights can be detected easily. This algorithm is also tested on a number of data sets that are infected with interference and in all the cases; it was successful in detecting and eliminating the interference bands. This algorithm also improves signal detect ability by using de-noising techniques used during HHT processing. The power and Doppler values (moments) are estimated using FFT and HHT and median Doppler is plotted on Doppler power spectrum and compared.

VI. ACKNOWLEDGMENT

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Dr. N.Padmaja received B E (ECE) from University of Mumbai, India in 1998 and M Tech from S V University College of Engineering, Tirupati in 2003 and Ph.D from S V University in the area of Atmospheric Radar Signal Processing in 2012. Currently she is working as Professor, Sree Vidyanikethan Engineering College (Autonomous), Tirupati. India. She has 20 years of teaching experience. She has published 43 technical papers in various reputed International Journals & conferences. Her areas of interests include Signal and Image Processing, Communication Systems. She is Life Member of ISTE, IETE, IAENG, ISCA and IACSIT. She is Member, Review Panel of various International Journals. She served as Technical Session Chairs, Technical Program Committee member and delivered key note address in various National and International Conferences. She is working for two projects funded by ISRO and DST and also serving as Mentor for DST Project under WOS scheme worth 90 Lakhs.

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She served as Executive Council member, and presently serving as Treasurer, IETE, Tirupati center. She received Best Teacher Award at C R Engineering College and Best Citizens of India Award from International Publishing House, New Delhi. She conducted several Workshops, conferences and Faculty Development Programs for the benefit of Faculty. She is presently serving as President, Institute Innovation Council, SVEC under MHRD Innovation Cell.

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