Radar Signal Processing using New Algorithm and Advanced Techniques

Synopsis

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By

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Radar probing of the atmosphere entered a new phase in early seventies through the pioneering work of Woodman and Guillen demonstrating that high power VHF radars offer a powerful means to explore the structure and dynamics of the middle atmosphere with unprecedented height and time resolutions given by (1). Their original work, employing the Jicamarca radar, led to the concept of Mesosphere-Stratosphere-Troposphere (MST) radar and this class of radars has come to dominate the scene of atmospheric probing over the past few decades.

MST radar/wind profiler is an excellent device used for atmospheric probing in the regions of Mesosphere, Stratosphere and Troposphere covering up to a height of 100 Km given by (2). It is also used for ionospheric studies above 100 km. Indian MST radar is one among this type of radars situated at Gadanki (13.5° N, 79.2° E).

Identification of atmospheric echoes and estimation of the three spectral moments is most important for the study of dynamics and turbulence of the atmosphere by (3),(4). Generally signal detection is carried out by identifying the largest peak in the Doppler power spectrum adopted by (5). From the largest peak three first order moments are estimated. This method may generate erroneous values of moments in the weak SNR region and the regions of clutter/interferences. There are different methods used for rejecting erroneous values after the estimation of the moments. Since these algorithms work mostly on the moments...
values, they may not always represent the most probable Doppler signal. Moreover these methods lead to a reduction in time resolution due to statistical averaging by (6), (7), (8).

In general signal analysis starts with power spectrum computation under the presumption that signal is stationary and the process is linear. Characterization of signals and developing a correct model to derive parameters has ever been a problem in the signal processing. There are different models formulated for characterizing the signals. Since the medium under study is very difficult to model, indirect methods were used to characterize the signals.

The thesis “Signal Analysis and Filtering Techniques Applied to Atmospheric Radars” presents signal processing and analysis techniques applied to extract and characterize the signals and estimation of parameters by new signal processing algorithms. It also presents a design of autonomous interference filter for removing the interference like signals from the radar back scattered returns.

The signals received from MST radar sometimes get contaminated with interference signals received from other objects or generated within the system through arcing of high power devices. There are Multiple interference bands with different characteristics observed in the power spectra, which contaminate the wind information and other atmospheric signals. An autonomous interference detection and filtering algorithm has been developed to remove interference bands generated in the
Doppler spectra of Mesosphere-Stratosphere-Troposphere (MST) radar signals. The technique, implemented with the MST radar at Gadanki is based on identifying the interference like band signals using a statistical signal variance approach for fixing the amplitude threshold through which detecting the interference frequency and design an adaptable notch filter to filter the undesired frequency bands by (9). The autonomous interference detection and filtering algorithm is applied to various cases and it is found that interference signals are removed effectively leaving behind original signals. By this approach effective number of signal samples obtained is increased which helps to improve the temporal resolution. This is the first time that this type of approach and algorithm development is carried out for wind profilers/MST radar. This work has been accepted for publication in the “IEEE journal of Geoscience and Remote Sensing” (in-press).

Signal analysis is a necessary part in pure research and practical applications. Imperfect as some data might be, they represent the reality sensed by us. Consequently, signal analysis serves two purposes: to determine the parameters needed to construct the necessary model, and to confirm the model we constructed to represent the phenomenon. Unfortunately, the data, whether from physical measurements or numerical modeling, most likely will have one or more of the following problems:
The total data span is too short;

The data are non-stationary; and

The data represent non-linear processes.

Although each of the above problems can be real by itself, the first two are related, for a data section shorter than the longest time scale of a stationary process can appear to be non-stationary. Facing such data, we have limited options for using the analysis.

The type of analysis to be applied is highly subjective when system (Generation process) is unknown. This method, adopts the trial and error, which supports best output in a given situation. The echo received from MST radar which represents atmospheric background information is considered to be generated through a random process. There are different approaches adopted by different people for analyzing the data and interpret the results. So most of the approaches aim to enhance Signal to Noise Ratio (SNR) for improving the detectability. The most common approach is the Fast Fourier Transform, which is the simplest and straightforward among all the methods.

A new signal analysis method based on the Empirical Mode Decomposition (EMD) method, which will generate a collection of intrinsic mode functions (IMF) is applied to the MST radar back scattered echoes. The decomposition is based on the direct extraction of the energy associated with various intrinsic time scales, which is the most
the system. It is expressed in IMF’s that, they have well-behaved Hilbert transforms, from which the instantaneous frequencies can be calculated. Thus, it was said that any event could be localized on the time as well as the frequency axis. The decomposition can also be viewed as an expansion of the data in terms of the IMFs. Then, these IMF’s, based on and derived from the data, can serve as the basis of that expansion which can be linear or non-linear as dictated by the data, and it is complete and almost orthogonal. The new method of signal analysis for non linear non-stationary process is called Hilbert-Huang Transform (HHT) by (10). An algorithm for HHT based data analysis of MST radar back scattered echoes has been developed and detailed analysis is carried out. The study brought out that the significant part of the signal has nonlinear and non stationary characteristics. One of the main heritage processing tools used in scientific data analysis is the Fourier Transform and its digital analogue, the Fast Fourier Transform (FFT). The Fourier Transform (long-time existence) and associated FFTs carry strong a-priori assumptions about the source data, such as linearity and stationariness. Natural phenomena measurements are essentially nonlinear and non-stationary. The accommodation of this fact in FFT-based analysis often involves using more data samples to assure acceptable convergence and non algorithmic procedural steps in the interpretation of FFT results. Wavelet-based analysis may yield some improvement over the FFT
non-stationary data, but it retains the limitation of requiring the data set to be linear. Wavelet methods may also prove inadequate because, although wavelet is well-suited for analyzing data with gradual frequency changes, its non-locally adaptive approach causes leakage. This leakage can spread frequency energy over a wider range, removing definition from data and giving it an overly smooth appearance. The HHT algorithm developed further is used for making a comparative study signal analysis approaches such as FFT. This type of analysis is carried out for the first time on atmospheric radar signals. A comparison study on two different transform, FFT and HHT is carried out by (11). *This work has been presented in the International Radar Symposium-2007 (IRSI-2007) and published in the proceedings of the IRSI-2007.*

Radar Interferometer technique in spatial domain basically provides information on the angular position of the discrete scatters and their aspect sensitivity to the radar backscatter in the vertical plane containing the interferometer baseline. It is also possible to derive the drift of the scatterers along the direction of the baseline by tracking their positions as function of time. The technique has been used extensively for studies on plasma irregularities in the ionosphere by (12),(13).

A study on lower atmospheric radar signals during a severe convective event using spatial domain interferometry technique is carried out. Necessary algorithms were developed for the analysis of signals
During convective event atmosphere is highly turbulent and wind field will be changing very fast in time and space. There is a strong updraft and down draft of mass observed along with heavy precipitation during the event. This will lead to generation of multiple echoes within the radar observational volume. Due to its complexity, the extraction of information is very difficult and could not reveal desired information by using conventional technique such as Doppler Beam Swinging and the signal extraction through power spectral analysis adopted by (14). A new approach is expressed that is using Space Domain Interferometry (SDI) technique to extract the information. Using SDI, coherence and phase of the bi-modal signal, unique characteristics are shown which help in identifying the velocity of clear air and precipitation echoes. The high coherence and linear phase shown in cross spectral analysis helps to identify the clear air and precipitation echoes in a highly complex signal pattern. Large number data sets were tested with this technique and found to be successful in identifying the multiple peaks echoes in a highly disturbed atmospheric environment. This is the first time that this kind of analysis is carried out for extracting the wind information during the disturbed atmospheric condition. *This work is ready for submission to journal.*
This section summarizes the contents of this thesis and the details of each chapter given is below

**Chapter-1** mainly deals with literature survey related to the research work, about the signal processing applications and how far various signal processing techniques are applicable for Radar signal processing mainly in MST Radar applications.

**Chapter-2** presents a detailed description of observational instruments used for this study. Details and system description of MST radar are presented in block diagrams. Method of data acquisition and signal processing steps involved are also explained.

**Chapter-3** mainly deals with the practical problems on data analysis when the signals are contaminated with interference and signal to noise ratio is poor. The algorithm developed “An autonomous interference detection and filtering algorithm for wind profiler” is discussed in details and the case studies are presented with advantages of the algorithm.

**Chapter-4** presents new signal analysis technique for non linear non stationary process called Hilbert-Huang Transform (HHT) applied to MST radar back scattered echoes. The HHT algorithm developed, is further used for making a comparative study of different data analysis approaches such as FFT. A detailed comparative study and observations were presented in this chapter.
new signal analysis approach adopted when the atmosphere is highly disturbed and the multiple echoes received during convection and precipitation. The conventional approach of Doppler Beam Swinging (DBS) techniques for extracting wind information failed during these kind of observations. Spatial Domain Interferometry (SDI) observation and analysis of the signal using cross spectral technique are adopted. This study demonstrates the new analysis technique which has considerable advantage in detecting the signal in a complex environment.

Chapter-6 summarises the study carried out for the thesis. The advantage of using the new adaptable filtering technique and its usefulness for wind profiler is discussed. The new analysis approach for non-linear, non-stationary signals and cross spectral analysis on SDI based observation with emphasis on atmospheric radar back scattered echoes are also discussed. The future scope on this study is also a part of this chapter.

Autonomous interference detection and filtering algorithm is developed and successfully tested on the signals received from atmospheric radar. The algorithm is applied to a number of data frames that are contaminated with interference and in all cases algorithm could detect and remove the interference bands. This interference detection and filtering algorithm help in reducing the number of frames to be
It is demonstrated that HHT techniques are able to resolve frequency components with finer resolution. This is one of the important properties of this method applied to non linear and non stationary signals. It could be concluded that most of the atmospheric signal component received through radar falls under this category. This is a promising technique for enhancing the capability of detection of signals with finer details. All examples presented here testify the usefulness of this new method.

Spatial Domain Interferometry of atmospheric observation and cross spectral analysis have considerable advantage in analyzing the signal during the disturbed condition of the atmosphere where multiple targets (echoes) were present. The Example presented clearly demonstrates the capability of the technique and signal analysis for atmospheric radar applications.

References:


Publications: (Based on this research work)


