Signal Processing and Statistical Analysis of the Weather and Atmospheric Signals Using Radar Observations

A Thesis Submitted by

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Abstract

Higher Order Spectral Analysis (HOSA) is a very useful technique for analyzing the statistical relationships between several spectral components. HOSA can be defined in terms of Bispectrum as a third-order spectrum. This technique is useful for studying the statistical distribution of the signal when the additive noise sources are Gaussian in nature and also for studying the presence of nonlinearities in the signals. In some cases, the deviations from the Gaussian shape of the Doppler power spectrum can be considerable during severe weather conditions (due to the presence of strong wind shear and turbulence patterns), which exhibits skewed, sharp and bimodal signatures. The presence of turbulence in the atmosphere makes the process into nonlinear due to the wavenumber interactions between the eddies in a turbulent flow. Earlier studies used Bispectrum measurements to experimentally study the spectral energy transfer due to wavenumber interactions in a turbulent flow. Wavenumber triad interactions result from the quadratic nonlinearity of the Navier–Stokes equations. They are the fundamental energy transfer mechanism in fluid flows and manifest in Fourier space as triplets of three wavenumber vectors. To determine the strength of such interactions, one must measure the third-order spectra, commonly called Bispectra. One of the main reasons to consider HOSA on weather and atmospheric signals is to characterize the Doppler spectrum obtained through the backscattered echoes, which are generally skewed and have multiple peaks. The analysis also identifies deviations from Gaussianity and performs well in noisy environments. This technique will identify and detect the signals and better estimate moments for further processing. Also, it is useful to study the Bispectrum in turbulence measurements to investigate certain nonlinear properties, such as spectral energy transfer. Therefore, atmospheric signals have been considered to investigate the nonlinearities in the backscattered signals.

The main objective of this thesis is to analyze the weather and atmospheric signals to know their statistical distribution and find out any deviation occurring from the normality. It is also to investigate how the Bispectrum performs well under noisy conditions. This thesis also aims to study the nonlinearities present in the backscattered signals obtained from the MST radar.

The bispectrum technique has been applied to the complex time series data derived from a Polarimetric X-band Doppler Weather Radar (DWR) to understand the statistical distribution of the signals and the deviations from the Gaussian shape of the Doppler spectrum. The results of this analysis are compared with conventional techniques like the Fourier method and pulse pair technique. It is observed that through the bispectrum approach, the Gaussian noise components are

significantly removed from the backscattered signals and improves the detectability of the weather signals under noisy condition.

The backscattered signals from MST radar arise from the turbulence induced irregularities in the refractive index gradients. To study the presence of nonlinearities in the atmospheric signals, a novel approach has been proposed for the measurement of turbulent energy dissipation rate (ε) from Nonlinear Index (NLI) based measurements using the Higher Order Spectral Estimation (HOSE) technique. The Bicoherence obtained by this method has been applied to the backscattered signals received from the Mesosphere, Stratosphere and Troposphere (MST) radar, Gadanki. Here we considered both convective and clear air atmospheric observation for the analysis and calculated the Nonlinear Index (which represents the amount of nonlinearity in signals) for each range bin and observed that the index of nonlinearity indirectly provides information about turbulent intensity. An empirical relationship between the nonlinear index and turbulent energy dissipation rate has been established through regression models. The results of the turbulence energy dissipation rate (ε) calculated from the nonlinear index have been compared with the turbulence energy dissipation rate (ε) calculated from the spectrum width based method.

This thesis also developed an algorithmic approach to remove the noise and the ground clutter for weather signals to obtain the best quality of radar products such as Reflectivity, Velocity, and Spectrum width. Proper detection and estimation of signal and noise power measurements are important to generate the best quality of meteorological data products. Noise will be generated when the antenna intercepts the thermal radiation from various sources, including the sky, sun, ground, precipitation and man-made radiators, and it is constructively added to the receiver internal noise. In order to obtain the best quality of radar products, it is desirable to compute meteorological parameters by estimating noise power and removal of ground clutter. In this paper, an attempt has been made to study the Empirical Mode Decomposition (EMD) denoising techniques on weather radar signals in the presence of noise and ground clutter. EMD method is a time domain technique; it decomposes the signals into Intrinsic Mode Functions (IMF). Three different methods of EMD based denoising techniques have been considered and applied to the weather signals to check the best performance of the denoising technique and remove clutter. Limitations and advantages of these methods are brought out. In order to overcome the limitations of these approaches, we modified the techniques by adapting correlation based measurements. Moments have been estimated from these techniques and compared with the conventional methods like Pulse pair and Fourier based spectral moments.