RADAR SINGAL PROCESSING FOR THE APPLICATION OF ATMOSPHERIC WIND PROFILING

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ABSTRACT
The 1280MHz wind profiler is introduced with key features include a state-of-the-art digital receiver system and modern peak detection algorithms for obtaining high quality wind estimates, even in the presence of clutter at NARL, Gadanki near Tirupati Atmospheric signal processing deals with the processing of the signals received from the atmosphere when manually stimulated using atmospheric Radar. In this paper a review of statistical signal processing and data analysis methods used in low atmosphere experiments is attempted. Effectiveness of coherent integration in reducing data rates is discussed. For detecting weak Doppler artifacts in returns, spectral analysis of radar signals using time averaged periodogram is suggested. Estimation of signals parameters through spectral moments is reviewed. The performance of the system is compared with Radiosonde, which is at NARL, Gadanki, near Tirupati, A.P, INDIA. MATLAB code is developed for the signal processing of low atmospheric recorded data i.e., for off-line data processing.

INTRODUCTION
The Earth’s atmosphere is highly dependent upon the instruments we use for measuring it. The parameters of primary interest are temperature, pressure, humidity, precipitation and wind. Meteorological instruments have been refined over the years and routine surface measurements of these parameters have been made throughout the world since the nineteenth century. However, it was not until this century that we began to get a systematic look at the space and time variability of the atmosphere as a function of height above the ground. A significant advance in this area was made some 50 years ago with the development of Radiosonde (GPS balloon sonde) a device carried aloft by a balloon to measure temperature, pressure, and humidity and transmits these data back to a ground station. By tracking the motion of the balloon, the winds aloft could also be determined. The Radiosonde has become the standard instrument for upper-air instruments and today approximately 800 stations around the world release them on a regular basis – usually every 12 hours. This is not sufficient to define the significant smaller-scale weather events. Even though Radiosonde are inexpensive, the relatively high cost of maintaining balloon launching and tracking facilities has precluded more extensive use. Development of remote sensing technology offers a solution to this problem. In particular it is now possible to measure vertical profiles of the wind on a nearly continuous basis with accuracy better than that normally obtained with most balloons, and more economically. These revolutionary instruments are known as wind profiling radars (or wind profilers).

CONCEPT OF WIND PROFILER
The basic concepts for wind profiling radars are now well developed and are in wide spread operational use. The desire for excellent low-level performance from a compact system to complement VHF Wind profiler led to the development of 1280MHz system by the National Atmospheric Research laboratory (NARL), Gadanki, near Tirupati, A.P, INDIA.
The low-power UHF systems have found widespread use in air quality monitoring, research and operational applications. However, the design of most profilers operating at UHF frequencies, boundary layer profilers in particular, now date back about 10 years. The last decade has seen considerable advances in affordable state-of-art digital signal processing (DSP) technology allowing, for example, fully digital transceiver systems and digitization of the radar signal at intermediate frequencies. These advances allows for the system that is less sensitive to interference, and for application of technologies, such as pulse coding, which can be designed into the system from the start.

PROFILER HARDWARE
The NARL has proposed a 1280MHz wind profiler system. The heart of the profiler is a fully digitized receiver system. The system will be state-of-the-art in its class of wind profiling radars. The system, basically aimed to serve the research applications, will have flexibility in configuration and facilitate multi-mode operations. The block diagram of UHF wind profiler is shown in the below figure and with brief description of each subsystem.
The master controller, which is PC-based one, facilitates the user to set the experimental parameters such as pulse width, IPP, number of coherent integrations, range window etc. It controls the signal generation system and Digital receiver directly as they are located at the same place. A rubidium oscillator provides the free running high stable 10 MHz reference signal. The FPGA-based sync generator, controlled by the master radar controller, provides the required IPP (inter-pulse-period) marker pulse. The 10 MHz reference signal is distributed to all other subsystems as clock/reference input.

The IPP marker is also fed to the FPGA-based timing control signal generator, which generates the Tx pulse, Blanking pulse, transmit/receive pulse, Tx on/off pulse, beam selector switch control signals. All these signals are sent to the remote driver unit located beneath the antenna array, where they are conditioned and distributed before reaching the target subsystems. The 10MHz REF signal is also sent to the out-door unit located near the array, where it is used as reference to generate the LO (1210 MHz) and RF (1280 MHz) signals. The LO signal is fed to the down converter where as the RF signal is pulse modulated and sent to the antenna feeder. The receive RF and TX RF signals are separated by a T/R switch. The Butler feed matrix serves two purposes. It distributes the input Tx RF Pulse to all TRM and also provides the progressive phase shift at the output ports, needed for beam tilting. The feed matrix is two-dimensional having 256 output ports. The Tx RF and Rx RF are switched between the input ports by the beam selector switches. Each input port of the Butler network corresponds to a particular beam direction.

The system employs 256 TRMs. Each TRM consists of i) T/R switch at the input, ii) Transmit section, iii) Front end Rx section, and iv) Circulator and dual directional coupler at the output. The TRMs are connected to the antenna element on one side and Butler beam-forming network on the other side. The transmit chain consists of an RF on/off switch, a driver amplifier and power amplifier. The front-end section consists of a limiter, blanking switch, and LNA. The antenna array under consideration consists of 256 micro strip patch antennas arranged in a 16x16 square matrix. The beam width is 4.5 deg and the SLL is about 13.5 dB. The inter-element spacing is 0.7 λ, which allows a grating lobe-free scanning up to 20 deg.

The received signal from the feeder network is given to the receiver system which consists of an RF down converter, IF amplifier chain and digital receiver. The IF chain consists of amplifiers, various switches, programmable attenuator and BPF. The digital receiver consists of an ADC card, and FPGA-based digital down converter, FIR filter, decoder and integrator. Digital receiver is connected to the PC by means of an Ethernet switch.

**SIGNAL PROCESSING**

The raw data received from the receiver is first subjected to DC removal. Processing involves FFT computation, estimation of mean Doppler, Doppler width, echo power and noise level for each beam direction. The three components of the wind vector are derived from the mean Doppler obtained from all the beam directions through a least mean square technique. The physical parameters are stored in an archival PC networked with the on-line analysis PC.

The MATLAB software has been used to allow for easy modification and inclusion of algorithm at all stages of data acquisition, processing, and display. The objective of signal processing is to extract the information existing in the radar echo by the way of directivity and estimating the amplitude and velocity of the scatters. The analysis is usually partly on-line and partly off-line. The on-line processing significantly compresses the data via time averages and usually produces power spectra and the off-line calculations involve parameter extraction. The purpose of off-line data processing is parameterization of the Doppler spectrum.

The complex time series of the decoded and integrated signal samples are subjected to the process of FFT for the on-line computation of the Doppler power spectra for each range bin of the selected range window. The Doppler spectra are recorded on a Hard disk for off-line processing. The detected quadrature signals are coherently integrated for many pulse returns which lead to an appreciable reduction in the volume of the data to be processed and an improvement in the SNR. The coherently integrated complementary pairs of coded signals are decoded for each range gate and added together to generate the final time series of the signal return for spectral analysis. The input data is to be normalized by applying a scaling factor corresponding to the operation done on it. This will reduce the chance of data overflowing due to any other succeeding operation. It is well known that the application of FFT to a finite length data gives rise to leakage and picket fence effects. Weighting the data with suitable windows can reduce these effects. Spectral analysis is connected with
characterizing the frequency content of a signal. FFT is applied to complex time series \( \{(I_i, Q_i), i = 0, 1, \ldots, N-1\} \) to obtain complex frequency domain spectrum

\[
X + jY = \frac{1}{N} \sum_{k=0}^{N-1} (h + jQ_i) \exp(-2\pi i k / N) \quad i = 0, \ldots, N - 1
\]

Power spectrum is calculated from the complex spectrum as

\[
P_i = X_i^2 + Y_i^2, \quad i = 0, \ldots, N - 1
\]

Incoherence integration is used to average the power spectrum number of times.

\[
P_i = \frac{1}{m} \sum_{k=1}^{m} P_{ik} \quad i = 0, \ldots, N - 1
\]

where \( m \) is the number of spectra integrated.

The advantage of incoherent integration is that it improves the detect ability of the Doppler spectrum. Next step is clutter DC removal. Due to various reasons the radar echoes may get corrupted by ground clutter, system bias, interference, image formation etc. The data is to be cleaned from these problems before going for analysis.

**NOISE LEVEL ESTIMATION**

There are many methods adapted to find out the noise level estimation. Basically all methods are statistical approximation to the near values. The method implemented here is based on the variance decided by a threshold criterion, Hildebrand and Sekhon (1974). This method makes use of the observed Doppler spectrum and of the physical properties of white noise.

**Parameter Estimation**

The extraction of zeroth, first and second moments is the key reason for on doing all the signal processing and there

\[
\frac{\text{Variance}(S)}{\text{mean}(S)^2} \leq 1
\]

by finding out the various atmospheric and turbulence parameters in the region of radar sounding. The basic steps involved in the estimation of moments, Woodman (1985) are given below.

Step 1:
Reorder the spectrum to its correct index of frequency (i.e. -f_{maximum} to +f_{maximum}) in the following manner.

Step 2:
Subtract noise level \( L \) from spectrum.

Step 3:
(i) Find the index of the peak value in the spectrum, i.e. \( P_i \geq P_i \) for all \( i = 0, 1, \ldots, N - 1 \)

(ii) Find \( m \), the lower Doppler point of index from the peak point.

i.e. \( P_i \geq 0 \) for all \( m \leq i \leq 1 \)

(iii) Find \( n \) the upper Doppler point of index from the peak point

i.e. \( P_i \geq 0 \) for all \( 1 \leq i \leq n \)

Step 4:

The moments are computed as

i) \( M_0 \) represents zeroth moment or Total Power in the Doppler spectrum.

\[
M_0 = \sum_{i=m}^{n} \tilde{P}_i
\]

ii) \( M_1 \) represents the first moment or mean Doppler in Hz

\[
M_1 = \frac{1}{M_0} \sum_{i=m}^{n} \tilde{P}_i f_i \quad \text{where} \quad f_i = \frac{(i - \gamma)}{(IPP \times n \times N)}
\]

iii) \( M_2 \) represents the second moment or variance, a measure of dispersion from central frequency

\[
M_2 = \frac{1}{M_0} \sum_{i=m}^{n} \tilde{P}_i (f_i - M_1)^2
\]

iv) **Doppler width (full) =** \( 2\sqrt{M_2} \) Hz

v) **Signal to Noise Ratio (SNR) =** \( 10 \log \left[ \frac{M_0}{(N \times L)} \right] \) dB

where

- IPP - is interpulse period in microsec.
- \( N \) - is the number of FFT points.
The prime objective of atmospheric radar is to obtain the vector wind velocity. The DBS method uses a minimum of three radar beam orientations (Vertical, East-West, and North-South) to derive the three components of the wind vector (Vertical, Zonal and Meridional).

To calculate UVW parameters, the Doppler frequency and range bin have to be expressed in terms of corresponding radial velocity and vertical height.

\[
\text{Height, } H = \frac{(c \cdot 13 \cdot \cos \theta)}{2} \text{ meters}
\]

\[
\text{Velocity, } V = \frac{(c \cdot f_0)}{2 \cdot f_c} \text{ or } \frac{f_0 \cdot \lambda}{2} \text{ m/sec}
\]

Where

- \( f_D \) = Doppler frequency
- \( \Lambda \) = wavelength
- \( \Theta \) = beam tilting angle

After computing the radial velocity for different beam positions, the absolute velocity (UVW) can be calculated.

\[
\begin{bmatrix}
V_X \\
V_Y \\
V_Z
\end{bmatrix} = \begin{bmatrix}
\sum \cos^2 \theta_c \\
\sum \cos \theta_c \cos \theta_h \\
\sum \cos \theta_c \cos \theta_h \\
\sum \cos \theta_h \cos \theta_h \\
\sum \cos \theta_h \cos \theta_h \\
\sum \cos^2 \theta_h \\
\sum \cos \theta_h \cos \theta_h \\
\sum \cos \theta_h \cos \theta_h \\
\sum \cos^2 \theta_h
\end{bmatrix}^{-1}
\begin{bmatrix}
V_0 \cos \theta_c \\
V_0 \cos \theta_h \\
V_0 \cos \theta_h
\end{bmatrix}
\]

Thus, on solving above equation we can derive \( V_X \), \( V_Y \), and \( V_Z \) which corresponds to \( U \) (Zonal), \( V \) (Meridonal) and \( W \) (Vertical) components of velocity. The plot of these wind vector velocities is shown in below figure for one scan cycle. The same process of calculations is used for other scan cycles. The wind velocities of UHF wind profiler output are compared with Radiosonde.

**CONCLUSION**

The signal processing associated with the UHF wind profiling Radar includes an algorithm for clutter suppression, moment estimation, windvector calculations. The wind velocity vector is calculated for low atmospheric region by recording spectral data from digital receiver and is compared with Radiosonde data.

**REFERENCES**


