적응배열 안테나를 이용한 기상 레이다에서의 클러터 제거

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Clutter Removal in a Weather Radar Using an Adaptive Array Antenna

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요 약

기상 레이다에서 급변하는 기상 상황에 관한 신뢰성 있는 정보를 추출하기 위해서는 해당 영역에서 높은 해상도를 갖는 풍속 측정이 필요하다. 그러나 정확한 펄스 페어 추정치를 얻기 위해서는 상대적으로 강력한 고정 및 이동 클러터들을 매우 효과적으로 제거하여야만 한다. 이러한 클러터 제거상의 문제점을 해결하기 위하여 간단한 위상배열 안테나를 적용할 수 있다. 모의 구현한 클러터 및 기상신호들을 이용하여 적응배열 안테나를 이용한 기상 레이다에서의 클러터 제거 능력을 분석하였다. 또한 적응배열 기상 레이다에서 얻은 펄스 페어 추정치와 원래의 추정치 값을 비교 분석하였다.

Key Words : Clutter, Weather Radar, Adaptive Array, Doppler Estimates

ABSTRACT

High resolution windspeed profile measurements are needed in a weather radar to provide the reliable information of rapidly changing weather conditions. However, it is necessary to remove both stationary and moving clutter to obtain the accurate pulse pair estimates. To overcome these problems, a simple adaptive array antenna may be applied to clutter removal. Using the simulated weather and clutter data, the clutter cancellation capability is analyzed for a weather radar with an adaptive antenna. The pulse pair estimates obtained from the adaptive weather radar are compared with those of the raw data.

Ⅰ. Introduction

The pulse Doppler radar is considered to have a great potential as a remote sensing device. Previous applications of pulse Doppler radar techniques in mapping severe storm reflectivity and velocity structure has been very successful[1,2]. High resolution windspeed profile measurements are needed in a weather radar to provide the reliable information of rapidly changing weather conditions. The commonly used pulse pair method is quite attractive when processing an enormous amount of weather radar data in real time since it is considered the fastest algorithm available[3-5]. However, it is necessary to remove both stationary and moving clutter to obtain the accurate pulse pair estimates. The use of the conventional pulse pair canceller or other high-pass Doppler filters may be effective for the removal of ground clutter but the moving clutter occurring from airplanes, vehicles or turbulent sea

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논문번호 : KICS2011-03-135, 접수일자 : 2011년 3월 4일, 최종논문접수일자 : 2011년 5월 27일

surfaces cannot be eliminated. To make matters worse, even the removal of stationary ground clutter is not an easy task because of Doppler spectrum spread due to antenna rotation and phase noise.

To overcome these problems, a simple adaptive array antenna may be applied to clutter cancellation. Using simulated weather and clutter data, the clutter cancellation capability is analyzed for a weather radar with an adaptive antenna. The pulse pair estimates obtained from an adaptive system are compared with those of the raw data.

Ⅱ. Adaptive Array

Reflector antennas are generally used in weather radar systems but the adaptive array may provide the more accurate weather information. In this analysis, The use of a simple rotating adaptive array with four vertically deployed slotted antennas is assumed for the performance analysis. Weather signals from the main lobe have same incident angles of zero at all array elements, but the clutter from the sidelobe has the nonzero incidence angle resulting in the different phase delay at each element as shown in Fig. 1. Therefore, the weight for each antenna element can be adjusted for the adaptive clutter cancellation which is called as the adaptive receiver beam forming making nulls in the direction of clutter returns.

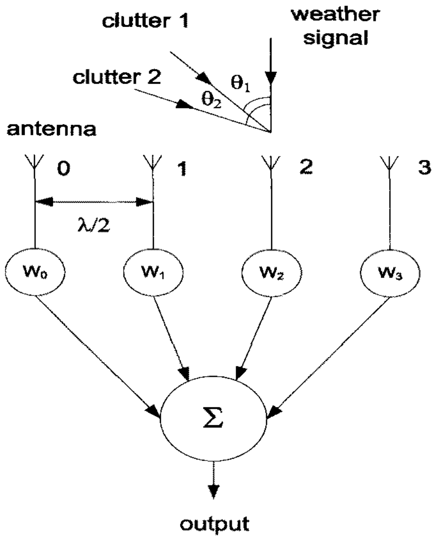

Fig. 1. A simple array structure with four antennas

Considering different phase delays of array elements according to the incidence angle, the clutter returns at each element are described by

$$C_m(k) = C(k)\exp(-jm\pi\sin\theta) \quad \text{where k=0,1}\cdots\text{N-1 and m=0,1,}\cdots\text{M-1} \tag{1}$$

In equation (1), the distance between elements is assumed to be the half wavelength and k and m represent the clutter sample number and the index of array elements respectively. Thus, the weather signal returns at the desired direction angle of zero can be written as Sm(k)=S(k). Since the received vector, X contains the clutter vector C, the weather signal vector S and the background noise vector N, it can be represented by

$$\mathbf{X} = [x_0, x_1, \ldots x_M]^T = \mathbf{S} + \mathbf{C} + \mathbf{N} \tag{2}$$

In determining the weight vector of the array elements W, the constrained minimum variance algorithm can be applied to maximize the signal to clutter plus noise ratio(SCNR)[6,7]. Using Lagrange multipliers, the weight vector can be obtained by

$$\mathbf{W} = \frac{\mathbf{M}_x^{-1}\mathbf{S}}{\mathbf{S}^H\mathbf{M}_x^{-1}\mathbf{S}} \tag{3}$$

In equation (3), the sample estimate of the covariance matrix Mx, is only available practically and it is given by

$$\hat{\mathbf{M}}_x = \frac{1}{N}\sum_{k=0}^{N-1}\mathbf{X}(k)\mathbf{X}(k)^H \tag{4}$$

Ⅲ. Simulation of Clutter and Weather Signals

The Doppler spectrum model of the clutter and weather signals should be determined to simulate the appropriate data. As seen from measurements, the clutter and weather signals can be modeled as Gaussian Doppler spectra having the different mean and width[8]. Using this power spectrum model, Inphase(I) and quadrature(Q) components of simulated weather radar data can be obtained, i.e.,

$$I(k)+jQ(k)=\frac{1}{N}\sum_{i=0}^{N-1}P_i^{1/2}\exp(j\theta_i)\exp(-j\frac{2\pi}{N}ik) \qquad (5)$$

Here, P_i represents the instantaneous power which includes the clutter, weather signals and the background noise. θ_i in (5) means the phase component having the uniform probability distribution. However, the probability density function of P_i is required to get the data. The instantaneous power of clutter or weather signals will have the exponential probability density function since their inphase and quadrature components can be described as complex Gaussian by central limit theorem resulting in Rayleigh probability distribution of the amplitude. Therefore, P_i can be described by

$$p(P_i)=\frac{1}{PM_i}\exp\left[-\frac{P_i}{PM_i}\right] \qquad (6)$$

where PM_i represents the power spectrum values of the Gaussian model. Using the uniform random variable, U_i, having values between 0 and 1, P_i can be written as

$$p(P_i)dP_i = p(U_i)dU_i \qquad (7)$$

Therefore, by integrating equation (7), the simulated data, P_i, can be obtained from the following equation.

$$P_i = PM_i \ln U_i \qquad (8)$$

From these P_i's, the representative I, Q data of the clutter and weather signals including the background noise can be generated as shown in (5). These data are processed and results are obtained using the simple adaptive array antenna. Fig. 2 and Fig. 3 show the typical simulated weather Doppler spectrum and its I, Q data respectively including clutter and the background noise.

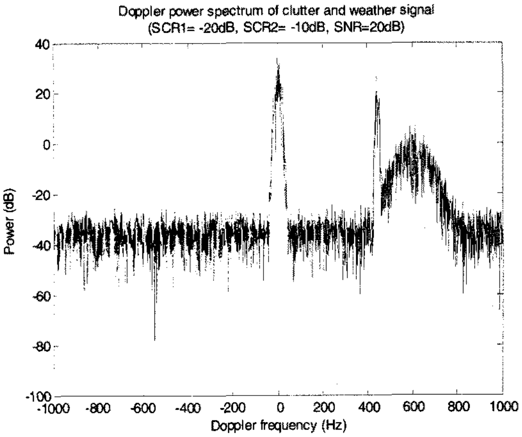

Fig. 2. A typical simulated weather spectrum with clutter and noise where SCR1 and SCR2 represent the first and the second weather signal to clutter ratio

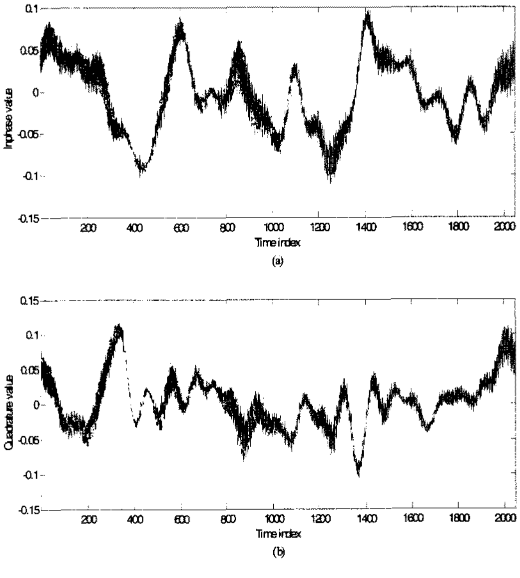

Fig. 3. Inphase and quadrature phase data of a typical simulated weather spectrum with clutter and noise

Ⅳ. Results of Pulse Pair Spectrum Estimation

For the simulation purpose, the pulse repetition frequency(PRF) and the frequency of the weather radar are assumed to have 2 KHz and 6 GHz respectively. Also, it is assumed that the receiving direction of weather signals is 0 degree and the incident angles of the ground clutter and the moving clutter are 22.5 and 10 degrees respectively.

Considering typical weather situations, the SCR and the SNR are chosen to have the range of -20~-30dB and 15~20 dB. The spectrum width of the clutter and the weather echoes are assumed to have values of 4~12 Hz and 40~60 Hz.

Fig. 4 shows the beam pattern of four elements array antenna obtained from the computed adaptive weight vector. As expected, deep nulls occur at the incident angles of the ground and moving clutters. In Fig. 5, the true mean Doppler frequencies and the pulse pair estimates of 26 range cells are compared. As seen from Fig. 5, the results show the quality of estimates is greatly improved with use of the simple array antenna structure. The pulse pair estimates of the spectrum width are also plotted in Fig. 5.

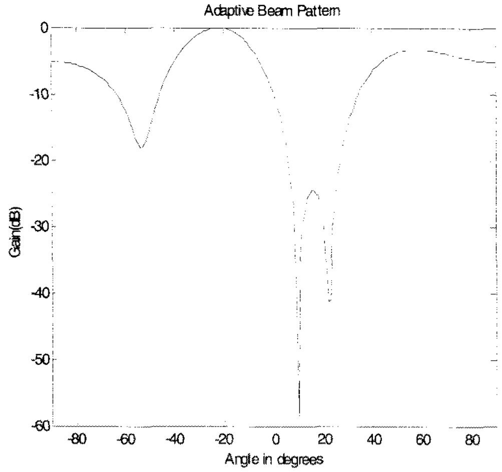

Fig. 4. The obtained beam pattern of the array for removal of both the ground and moving clutter

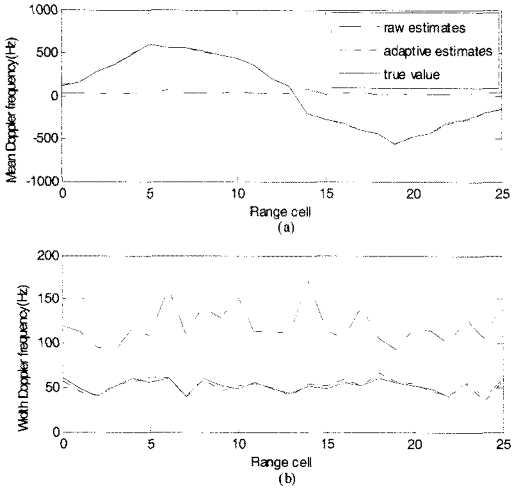

Fig. 5. The adaptive mean and width estimates compared with true values and the pulse pair estimates of raw data

It shows thevery promising results. Therefore, the suggested adaptive clutter cancellation method may help extract the more accurate weather information under the various clutter situations by adaptively determining the weight vector of the array elements.

V. Conclusion

Removal of the strong ground and moving clutters is essential for the accurate estimation of Doppler weather spectrum which may be very important in the detection of hazardous weather conditions. In this paper, the most commonly used pulse pair estimates are compared for the mean and the width of Doppler weather spectra.

As seen from results, the quality of estimates can be greatly improved by applying the simple adaptive array structure. This adaptive clutter removal is especially important in rapidly changing operation environments where the characteristics of both the ground and moving clutters vary fast.

Also, it shows that the reliable weather information can be extracted even under the moving clutter or the Doppler spread of the ground clutter since this simple array acts as a spatial filter by forming nulls in the direction of clutter arrivals.

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