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Review on various Wind Turbine Clutter Mitigation Techniques in Weather RADAR Systems

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ABSTRACT: Recently there has been rapid growth of wind farm installations. Many commercial utility scale wind turbines are built across the world for wind power generation. These large structures are reported to cause interference on nearby radars because their scattering and motional behavior. University of Oklahoma and National Severe Storm Laboratory scientists developed an automatic WTC detection algorithm which is necessary and the first step in any mitigation scheme. There are various models are developed which are having some applications including wind turbine detection, wind turbine modeling, spectral processing, clutter rejection etc. This paper gives the thorough analysis of WTC detection, characterization, modeling and mitigation techniques.

KEYWORDS: EM waves, Doppler shift, Range Doppler, Hydrometer, Point Spread Function etc.

I.INTRODUCTION

Compared to fossil fuels wind energy generated by wind turbine generator is being criticized over the world. Weather RADAR (RAdio Detection And Ranging) is used for detecting, locating precipitation and estimating its motions. It operates by transmitting an EM waves and receiving echoes from the target. Clutter [7] is referred to as any unwanted echo. WTC effects degrade the radar performance and saturate the radar receivers. While establishing a wind farm includes many considerations like consultation with various civil or military aviation interests because they may raise objectives. Wind turbines may be a threat to the safety of low-flying military aircrafts as well as they appear as a strong radar echo.

Besides than radar systems [7], wind farms can cause degradation to other existing electronic systems especially for television terrestrial broadcasting services. Static ghost in the picture or a cyclic variation of the brightness in the picture caused due to interference from wind turbines. It is hard for aviation safety authorities to give a clear and well founded decision on whether a particular proposed wind farm presents a safety issues or not due to which it restricts the areas available for wind farm development [4]. National Weather Service does not have the legislative authority for wind farm as compared to other federal bureaus because most affected radars are weather radars. The effects of wind turbines on radar system are as follows:

1. The magnitude of reflection from wind farms cause radar receivers to be driven to saturation. The parameters of wind turbine are given in TABLE I.

Parameters	Models		
	G58	G83	G90
Turbine rating (KW)	840	2100	2100
Rotation rate (rpm)	14.5-30.6	9-19	9-19
Tower height (m)	44-71	67-77	67-105
Blade length (m)	28.25	40.6	44

TABLE I. Wind Turbine parameters

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2. Doppler shifts caused by rotation movement of blades. Doppler shift increases from center to tip of the blade.

To improve and maintain radar surveillance it is necessary to mitigate the effects of wind farms on radar systems as specified wind farm configurations can be employed for the wind energy systems. Modifying the inside of the blades is one of the proposals [11]. But it is frequency specific method. Therefore efficient WTC methods are required. Depending on improving the radar's ability to discriminate between wanted and unwanted targets, WTC mitigation techniques have been proposed.

Amplitude thresholds, Doppler discrimination, constant false alarm rate [2] are some examples of WTC mitigation technique. Amplitude threshold is a set in the radar causing echoes below certain amplitude which are to be ignored. If the wanted targets expected to have a lower RCS than wanted targets, the amplitude of the unwanted returns can be expected to be lower than that of the specific target in amplitude thresholding. Wanted moving targets and unwanted static or slow moving targets can be discriminated by Doppler discrimination. To maintain radar performance CFAR is designed where clutter is present. This technique is not suitable for mitigating the clutter because the clutter threshold will eliminate the genuine target and clutter.

II. WIND TURBINE EFETCS IN VARIOUS SITUATIONS FOR DIFFERENT RADARS

1. Monopulse Secondary radars

Secondary surveillance radar [10] is used in air traffic control which detects and measures the position of aircraft i.e. range and bearing and also requests additional information like its identity, altitude from the aircraft itself. It offers great flexibility to adapt to the client necessities. Wind turbine presence affects the performance of mono-pulse secondary radar. When the integrated target emits its response, the azimuth can be computed partially obscured large obstacle such as a wind farm.

2. Primary Surveillance radars

In primary surveillance radars, air defense and air traffic control wind turbine include clutter which increase no. of unwanted returns, desensitization reduce probability of detection for target and tracking [10]. This radar is achieved by controller instructing an aircraft to turn and observing same on their display with the position of a particular return along a known track. They cause higher probability of false alarm and lower probability of detection [2]. They require enormous amount of power for radiation which ensures the detection of target.

3. Weather radars

Weather radar is a type of radar used to locate precipitation, estimates its type and calculates its precipitation. They are also called as pulse Doppler radar [5] which is capable of detecting rain drops and intensities of rain, snow, hail, and other weather phenomena. The rotating blades of wind mills can return the radar beam to the radar if they are in its path. As the blades are moving the echoes will have a velocity and can be mistaken for real precipitation. For weather radars the interference causes the misidentification of thunderstorm features and meteorological algorithm errors such as mesocyclone signatures and incorrect storm cell identification and tracking [10].

III. MITIGATION TECHNIQUES

Wind turbine clutter characterization or detection [5] is the first step towards development of wind turbine clutter mitigation techniques. The aim of WTC characterization is to create a model which will identify the radar clutter from weather radar data. Wind turbine clutter mitigation techniques are given below:

1. Fully Adaptive arrays

R. D. Palmer, B. Isom et al [10] proposed a solution using adaptive phased array radars for interference cancellation. To obtain a signal which represents the weather scattering field, the fully adaptive arrays are used. The WTC contamination near the ground is eliminated by using constructive and destructive interference of the pattern. To reduce the WTC they mention to retrofit the blades and tower of affecting turbines with radar absorbent material and other ideas which include shaping the turbines which scatter away the radiated energies from the radar and detection techniques to improve the sensitivity of radars. They also gave the numerical simulations using simulator which is shown in Fig.1. This simulator models the environmental and clutter field using point targets.

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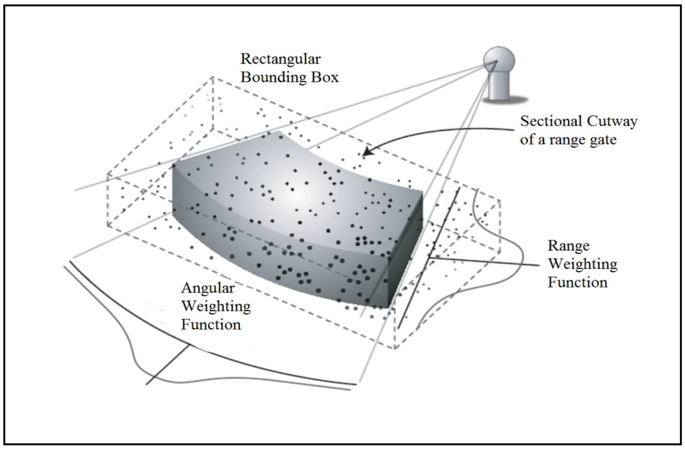

Fig. 1 Environmental and clutter field simulator model

To retrive an accurate representation of the scattering weather field the simulator of [11] was used which generates the time series signals. An illustration of simulator is shown in Fig. 1. For modeling environmental and clutter field simulator uses point targets. Advanced regional prediction system produces scattering and dynamic properties emulated by weather field by point targets. Fifty thousand point targets were used which model the environmental field who occupy a volume of approximately 7*7*5 km^3 with the radar located at 32 km away approximately. Radar observed the simulated event over 200 s duration at 25 s interval, 256 time series samples were collected during each scan.

2. Range Doppler Domain

Feng Nai, Robert D. Palmer and S. M. Torres proposed a signal processing technique to separate the WTC from the weather signal. Range Doppler domain [12] is 2 dimensional image which is plot of Doppler spectra containing a set of contiguous range gates. It is function of range r and Doppler velocity v denoted as S(r, v). The color scale in Doppler spectrum corresponds to signal power, horizontal axis is Doppler velocity and the vertical axis is radial distance as shown in Fig. 2. The aim of Doppler spectrum is that to estimate special information which is useful for mitigation technique.

The weather signal is continues in range i.e. the radial velocity and spectrum width from gate to gate is relatively constant. The continuity of weather signal in range is disrupted when WTC contamination occur which results in large jump in power level per frequency bin. Secondly the weather signal is narrowband while WTC signal is wideband. The goal of this mitigation algorithm [12] is to reduce the bias which is caused by WTC while estimating moments. Doppler spectrum is the distribution of radial velocities. Radial velocity is the first moment of weather signal which will identify the motion of a storm. Spectrum width is the second moment which is used to find the dispersion of hydrometers. Fig. 2 shows the Range-Doppler spectrum where the color scale refers to the signal power on pixel classification in the range-doppler spectrum of WTC non-contaminated gate to contaminated gate. False edges are removed by setting the length threshold in spectral estimation variance.

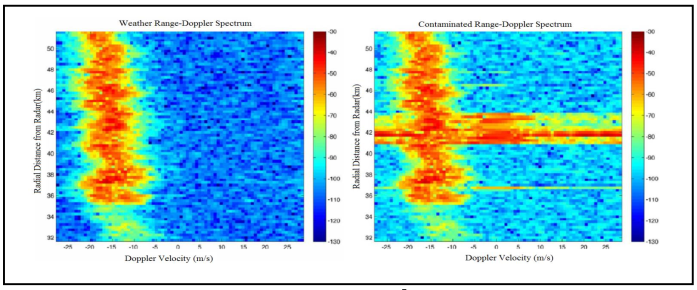

Fig. 2. Range Doppler Spectrum

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3. Auto-correlation Spectral Density

David A. Warde and S. M. Torres developed a new technique for spectral analysis. Auto correlation spectral density gives the phase information which is used to estimate spectral analysis of radar signal. The autocorrelation [3] estimates at a few small lags gives the meteorological variables which are provided by Doppler weather radar. Auto correlation is core of most weather radar signal processors. An autocorrelation spectral density based automatic estimator is proposed to produce unbiased estimates of the weather signal spectral moments. The effects of spectral leakage are illustrated by narrowband and wideband Gaussian signal with additive noise. Fig. 3 shows the power spectral density of these signals which approximates true PSD.

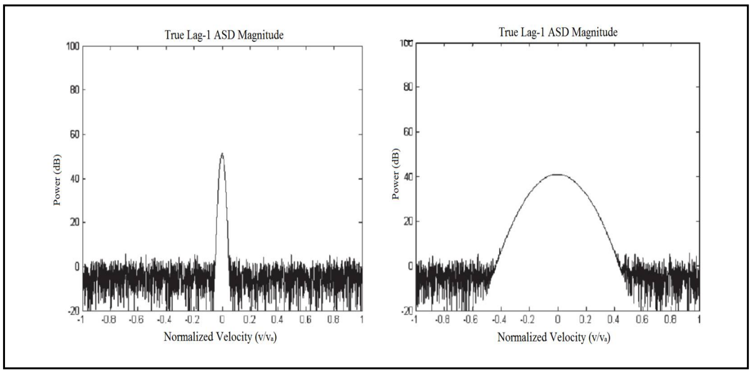

Fig. 3. Environmental and clutter simulator model

This estimator is computationally simple and is used for meteorological estimators in the time domain. ASD provides explicit phase information which exploited to identify and removes certain types of contaminants signals. The effects of other lags of the ASD in the context of staggered PRT are to be considered for further study.

4. Signal Decomposition

Morphological component analysis is used by Faruk Uysal et al [13] to decompose the backscatter from the radars into sum of oscillatory and transient components. Numerous approaches have been proposed to define a suitable mathematical model containing well documented time domain and Doppler signature of rotating objects. To represent real life wind farms more sophisticated modeling is required given in [13] and this will help to estimate the time varying Doppler presents real life wind farms and this will help to estimate the time varying Doppler present in the wind turbine clutter returns. Morphological component analysis relies on sparsity for which different domains should be identified correspondingly for representing component sparsely. Moving targets returns can be sparsely represented in FT domain on the other hand WTC echoes represented using STFT. MCA recovers the components WTC and moving target separately.

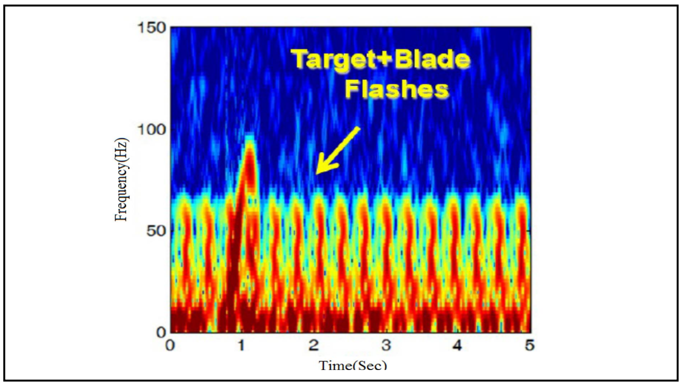

Fig. 4. STFT of recived echoes

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For fast and effective solutions of MCA problems split augmented Lagrangian shrinkage algorithm is mention. Then method of multiplier (MM) i.e. Augmented Lagrangian Method [13] (ALM) is used and solution is represented using matrix form. This algorithm is kwon as dual basis algorithm which separate out the moving target in WT like clutter. Custom built radar and micro-turbine were used for study and application of proposed method. The effectiveness of algorithm on other real data sets should be considered in future.

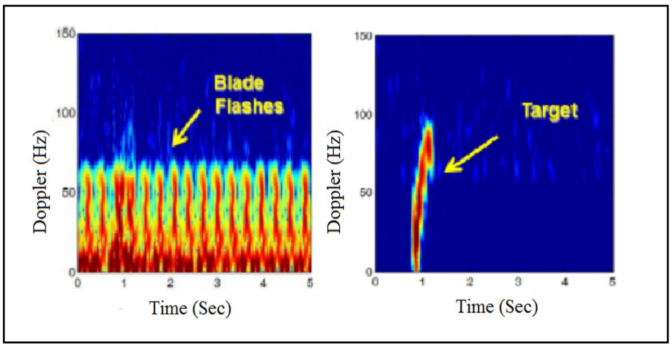

Fig. 5. Blade flashes and Target separated

5. CLEAN based WTC mitigation

An effective mitigation approach is proposed by Osman Karabayir et al [14] which is two stage approach. In first step approach average adaptive clutter map are generated through thresholding which are used to detect the locations of the WT. Second stage consists of subtraction of WT signal from matched filtered radar range profiles. All point scatterers are represented with a point spread function in the range profiles during matched filtering operation in the PDRs. These PSFs are dependent on the used pulse waveforms. PDR is a linear frequency modulated pulse waveform whose matched filtering output resembles to sine function. The duration of PSF is double of transmitted pulse duration. Hence signal contributions of a WT spread over many range cells depending on the duration of the PSF in one transmitted radar pulse of a range profile.

Effective WTC mitigation by ignoring only the range cells where the WTs are found is challenging problem. PSF have to suppress in order to mitigate WTC. Osman Karabayir et. al[14] proposed a CLEAN based algorithm in which range cells for the WTs are detected first by thresholding the average adaptive clutter maps and then PSFs of the WTs are subtracted from the range profiles using the CLEAN algorithm to obtain WTC free range profiles. The radar range profiles consist of larger structural dimensions clutter occurrence factor, high level scattering characteristics and rotational blades characteristics. By using these spectral and reflective characteristics, the locations of the interfering WTs are found out. For this an auxiliary range profile is constructed using the PSF of the transmitted waveform. They examine the performance of proposed WTC mitigation method for MTI based PDR systems using synthetic data. This method includes detection of WT locations using average adaptive clutter map [6] and mitigation of wind turbine signal by using CLEAN algorithm. The auxiliary range profile is subtracted from main range profile as shown in Fig. 6.

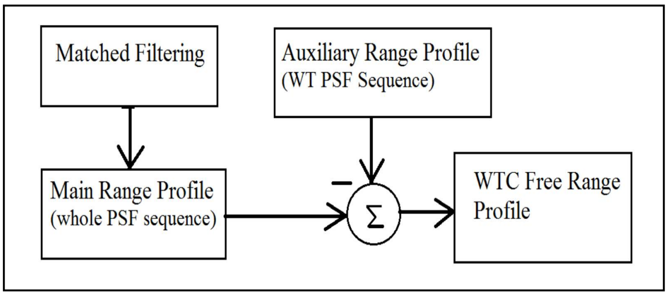

Fig. 6. Block Diagram for WTC free range profile

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VI. CONCLUSION

This paper describes a short study on various types of novel WTC mitigation techniques in weather radar systems. Although only some of the most recent methods were discussed in this paper, thus researchers can make a decision on which technique to choose depending on the performance of the algorithm and nature of the application developed and can carry on to improve some of these systems based on the guidelines provided each.

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