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SAR Imaging Using Fully Random Bandlimited Signals

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1 Introduction

A coherent ultrawideband (UWB) random noise synthetic aperture radar (SAR) has been developed and tested at the University of Nebraska. It has been experimentally shown that this type of radar is capable of extracting the phase and the amplitude of the backscattered signal, thus enabling us to create target profiles in the frequency domain. The use of fully random waveforms (bandlimited noise) as the transmit signal is analyzed in this paper. A UWB signal model is developed and radar signal processing is simulated to yield statistical characteristics of image formation using stochastic waveforms. The influence of UWB signal characteristics on the image quality is estimated and represented graphically.

2 UWB random signal model and simulations

Following the series of experiments that showed a clear potential for using ultrawideband random noise synthetic aperture radar as an imaging instrument [1], we proceeded with the development of statistical characteristics of the image formation.

The simulation of UWB random noise SAR process consisted of three steps: (1) creating an UWB bandlimited noise model, (2) creating an arbitrary target function (ATF), and (3) simulating radar backscattering and signal processing (correlation receiver) to obtain the image of ATF.

To derive a signal processing model in the radar, we first have to simulate an ultrawideband signal with Gaussian-distributed amplitude and uniformly distributed phase to achieve the specified bandwidth. If we represent the stochastic ultrawideband signal $P(t)$ as $A(t) \cdot sin(\omega_0 t + \phi_0(t))$, where ω_0 is the central frequency and $\phi_0(t)$ is random phase, then, following derivations in [3], we can deduce the following expression for instantaneous frequency Ω:

$$\Omega(t) = \sqrt{T_1(t) + T_2(t)}\ , \tag{1}$$

where

$$T_1(t) = (\frac{dA(t)}{dt} \cdot \frac{1}{\omega_0 \cdot A(t)})^2, \quad T_2(t) = (1 + \frac{d\phi_0(t)}{dt} \cdot \frac{1}{\omega_0})^2\ . \tag{2}$$

In our case, the received radar signal has amplitude $A(t) = \sqrt{I^2 + Q^2}$, where I and Q are in-phase and quadrature components of the received signal, while the random phase is a uniformly distributed function: $\phi_0(t) = \delta\omega \cdot t$, where $\delta\omega$ is a random variable. For simulation purposes, we used scaled values of frequencies and normalized values of amplitude. Having generated a vector of random amplitude and phase samples according to the signal specifications, we define the instantaneous frequency of the UWB random noise signal as:

$$\Omega = \sqrt{\left(\frac{\nabla A(t)}{\omega_0 \cdot A(t)}\right)^2 + \left(1 + \delta\omega \cdot \frac{2\hat{\phi} - 1}{\omega_0}\right)^2}, \tag{3}$$

where $\nabla A(t)$ is the gradient of amplitude samples vector, and $\hat{\phi}$ is uniformly distributed random variable in the range [0..1]. The results of modeling UWB random signal using this approach are shown in Fig. 1.

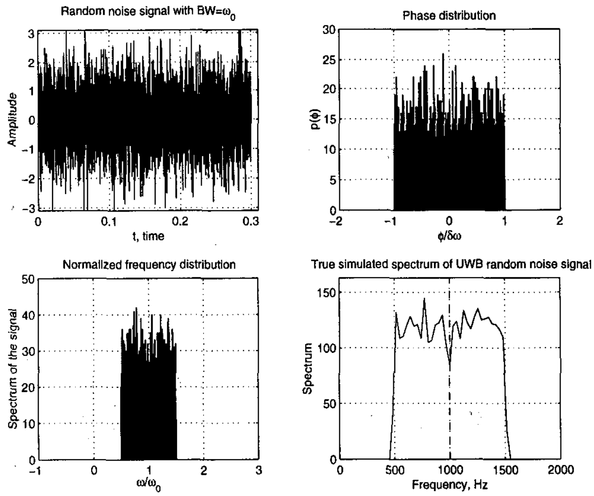

Figure 1: Modeling of UWB random signal.

Denoting this signal as $P(t)$, a generalized expression for the SAR measured echo signal is given by [2]:

$$s(u,t) = \sum_n f_n \cdot P\left(t - \frac{2\sqrt{x_n^2 + (y_n - u)^2}}{c}\right) \tag{4}$$

where f_n is the sample of the target function at n^{th} point on the target, t is the 'fast-time' (real time), u is in 'slow-time' domain (proportional to antenna movement), (x,y) are spatial coordinates.

If we define target function as

$$f(x,y) = \sum_n f_n \delta(x - x_n, y - y_n) \Longleftrightarrow F(k_x, k_y) = \sum_n f_n e^{-jk_x x_n - jk_y y_n} = F_t \tag{5}$$

where $F(k_x, k_y)$ is the Fourier transform of the target function $f(x, y)$, then the radar image function for the correlation receiver is given by:

$$F_{rx} = (F_t \cdot P_t) \cdot P_t, \tag{6}$$

where P_t is the spectrum of the transmitted signal and the bracketed expression is the spectrum of the received signal. To recover the target function, we perform spectral estimation of this signal and extract the image. Fig. 2 shows the image for both the noise-free case and noisy case (SNR = -3 dB), from which we infer that the ATF is recovered quite well.

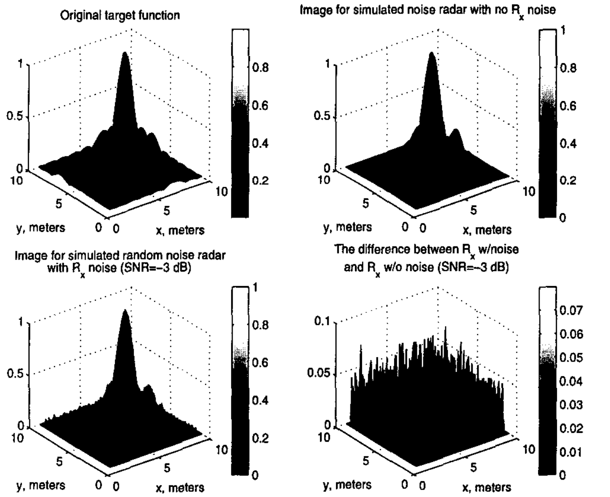

Figure 2: Modeling of target function recovery using UWB noise radar.

To perform radar processing for this simulation, the entire band of the UWB signal was divided into 128 frequency bins (since we cannot represent this signal model in the form of continuous spectrum). Obviously, the relative error between the target function recovered from noise-free backscatter and noisy backscatter will depend upon how well our signal model approximates that of the continuous UWB noise signal spectrum. The dependences of maximum and mean errors on the number of frequency bins (SNR was fixed at -3 dB) and SNR (number of frequency bins was fixed at 256) were investigated, and simulation results are shown in Fig. 3.

3 Conclusions

Ultrawideband random noise imaging radar performance was simulated and applied to the estimation of target function recovery. Correlation processing of backscattered and transmitted (and delayed) waveforms shows the potential for external interference and noise decorrelation from the radar images. Simulations clearly show that image improvement (based on relative error between simulated noise-free and noisy radar images) is directly proportional to the accuracy of continuous spectrum of UWB noise signal approximation, and to the SNR.

4 Acknowledgements

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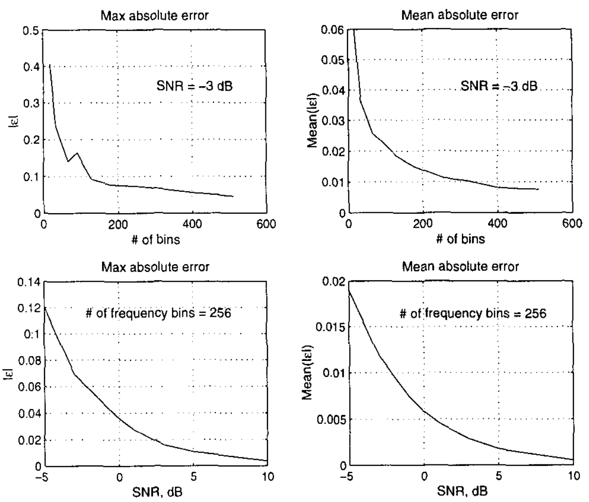

Figure 3: Error dependence upon number of frequency bins and SNR.