

# Small target detection from a drone-based phased-array radar

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## Abstract

In the recent years, small UAVs have become accessible for military, commercial and leisure activities. This comes with an increasing apprehension concerning their hazardous and illicit misuses. Radar systems have proved good capabilities for UAV surveillance, but small target detection still remains challenging and subject to active research. In this perspective, the present work deals with clutter mitigation and small target detection using phased-array radar and adaptive processing. The main contribution is the simulation of realistic small target and clutter data, and then the application of adaptive clutter mitigation and detection techniques, the goal being to improve the detection performance for small targets in adverse clutter environments.

## 1. Introduction

Small UAVs have become broadly used and their detection in complex environments is still a challenging task. The present work is conducted within the framework of the DOREDO project, aiming at detecting and localizing small obstacles such as light aircrafts and drones. The antenna system is a cylindrical array consisting of two sub-systems: The bearing system composed of a 24-column circular antenna allowing acquisitions in 360°, and the elevation system consisting of four columns, each one composed of 6 antenna patches. The system is under elaboration and the aim of the present paper is the simulation of realistic signals following the system characteristics for small target detection scenarios, and then performing signal processing and evaluating detection algorithms on the generated signals. This work is of paramount importance for applications such as radar system design. Its aim is twofold: on the one hand improving the simulation of realistic small target and ground-clutter signals, and on the other hand assessing the performance of adaptive array processing for clutter suppression as well as target detection. The paper is organized into four main parts: first the simulation of transmitted and received target signals is presented. Subsequently, CFAR target detection is assessed. Then the integration of realistic clutter statistics is addressed. The last section deals with adaptive array processing for clutter mitigation.

## 2. Transmitted and received target signals

Simulation of the main transmission and reception blocks for an X band airborne pulsed radar is performed. The emphasis is laid on the elevation system composed of a 6-element vertical Uniform Linear Array (ULA). Acquisitions are performed during a coherent processing interval (CPI) of 125 pulses and the generated waveform corresponds to the linear frequency modulated signal called chirp [1]. Raw I/Q complex data are then generated by considering the spatial delay between the array elements, phase and amplitude distortions, platform motion as well as thermal noise. In order to simulate realistic radar returns from targets of interest, the Radar Cross Section (RCS) from UAVs such as the DJI 3 drone have been measured in the anechoic chamber at ENSTA Bretagne. Assuming these RCS measurements, the received power is computed using the radar range equation.

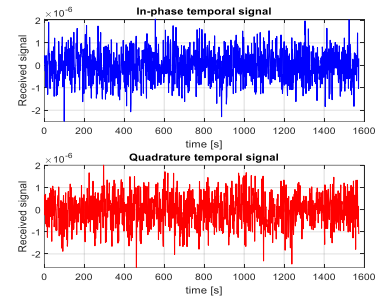


Figure 1: Generated IQ signals on array element for a target with RCS= -10 dBm<sup>2</sup>, embedded in thermal noise. The SNR on each antenna element is equal to -31.5 dB

Figure 1 illustrates an example of IQ signals generation for a single array element. The simulated scenario consists in a small target ( $RCS = -10 \text{ dBm}^2$ ), with a transmitted power of  $P_t = 46 \text{ dBm}$ , embedded in thermal noise. The SNR at the output of one antenna element is equal to  $SNR = -31.5 \text{ dB}$ , which is very low for target detection. In order to improve the SNR, beamforming is first performed by summation of the temporal signals from the 6 channels. Then integration of the 125 pulses and range compression are performed. This processing yields to an improved SNR of the order of 16 dB.

## 3. CFAR detection

CFAR (Constant False Alarm Rate) detection methods consist in computing an adaptive threshold using a sliding

window while maintaining a constant false-alarm rate (CFAR) [2]. In addition to the original CA-CFAR (Cell Averaging CFAR) method, other CFAR variants have been implemented and tested against the generated signals. An example of the interest brought by the SO-CFAR (Smallest of CFAR) compared to the CA-CFAR algorithm is illustrated in figure 2. Three targets are present and two of them are closely spaced. The further target is accurately detected by both CA-CFAR and SO-CFAR. However, for the two closely spaced targets, CA-CFAR (top figure) fails at detecting the lower SNR one, as the threshold is artificially increased by the interfering target present in its reference window. SO-CFAR algorithm (bottom figure) overcomes this limitation and correctly detects both targets.

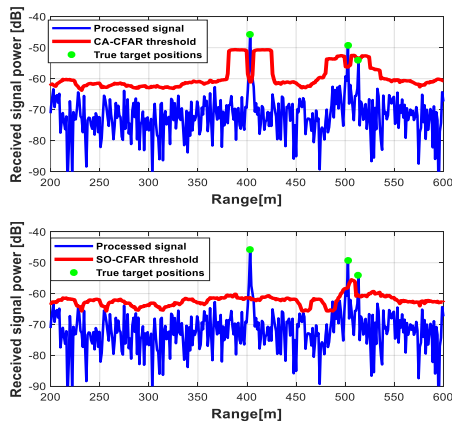


Figure 3: CFAR detection for the three targets. CA-CFAR (top figure), SO-CFAR (bottom figure)

#### 4. Clutter signals

In the previous sections, only thermal noise was considered. For an airborne radar looking downward, terrain scattering is usually the major source of clutter that can cause important degradation in probability of detection. Terrain clutter encompasses several categories that vary in characteristics such as spatial homogeneity, nature of the overlying media (vegetation, snow...), nature of the substrate (water, soil, ...) etc. Our work emphasizes on rural areas and thus considers clutter originating from trees, grasses, short vegetation and road surfaces. From a radar detection standpoint, ground clutter can be perceived as a distributed target that consists in a large number of randomly distributed scatterers. Due to its fluctuating nature, we resort to statistical analysis of the backscattering cross section per unit area, commonly called the backscattering coefficient and denoted  $\sigma^0$ , for which several statistical models have been proposed in the literature, such as the Rayleigh, Log-normal, Weibull and Gamma models. Note that the statistical parameters of the underlying distributions vary with sensor parameters (frequency band, polarization, acquisition geometry...), as well as the terrain nature, namely its geometrical and dielectric properties. In order to incorporate realistic clutter estimations, our simulations integrate distributions based on real clutter measurements reported in [3,4]. The authors document one of the most extensive series of measurements using different sensors covering various types of land

surfaces over a large range of operating frequencies and incidence angles. Several experiments were performed following a variety of specifications including the radar platform (Airborne, Spaceborne, arch Mounted, truck, ground-based), frequency bands (L/S/C/X/Ku/Ka bands) and ranging methods (FMCW/Doppler/Pulse radars). In our work the emphasis is laid on X band pulse radar airborne data from vegetation. For illustration, figure 3 shows the frequency of occurrence of different  $\sigma^0$  values for a terrain composed of grasses at a moderate incidence angle of  $40^\circ$ , in comparison with a Weibull distribution fit.

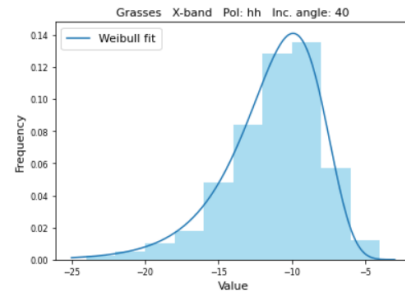


Figure 3: Example of  $\sigma^0$  histograms for a terrain composed of grasses at a moderate incidence angle of  $40^\circ$ , in comparison with a Weibull distribution fit.

#### 5. Adaptive array processing for clutter rejection

In airborne radar, platform motion induces a shift in ground returns in both range and angle, as well as a spreading in the Doppler domain, potentially leading to a masking of targets of interest that can be perceived at slow speeds comparable to clutter measurements. Space Time Adaptive Processing (STAP) [5] is a processing technique that exploits both the spatial and temporal dimensions of the signals received by an antenna array. This processing allows to take advantage of the two-dimensional space-time properties (and thus of the angle-frequency coupling) of the received signals, which significantly improves the performance by providing coherent gain on the target signal-to-clutter ratio. Typically, the data from several range gates near the range gate of interest are used and a training strategy is defined to provide an estimate of the clutter statistics. Afterwards, an adaptive weight vector is computed based on this estimate and applied to radar data to perform clutter suppression.

#### References

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