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Sense-Through-Foliage target detection using UWB radar sensor networks

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A R T I C L E   I N F O

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A B S T R A C T

In this paper, we propose two signal processing approaches to detect the target obscured by foliage based on real data collected by an Ultra-wide band (UWB) radar sensor. One is a differential-based four-step signal processing approach that estimates and offsets the impulsive clutter; the other approach employs short-time Fourier transform (STFT) to distinguish the target from foliage clutter. Both of these approaches provide better detection performance compared to the common 2-D image algorithm used for UWB radar. From time to time, due to the significant pulse-to-pulse variability of the foliage clutter, neither differential-based nor STFT approach can detect the target. In this case, we propose radar sensor network (RSN) and a RAKE structure in addition to the previous signal processing approaches for data fusion. The result shows that accurate detection can be achieved. Numerical performances have been analyzed for both cases in terms of probability of detection and probability of false alarm.

1. Introduction

Detection and identification of objects that are embedded in a strong clutter (e.g., foliage, soil cover and buildings) is of interest to both military and civilian research. The efficient and accurate detection provides a broad range of applications, such as locating weapon caches during military operations and rescuing people from natural diasters. Currently the detection of targets, such as human, vehicles and weapons that are hidden in foliage is still a challenging issue due to the low detection and high false alarm rate. This is mainly due to the following facts:

1. Given multipath propagation effects of rough surfaces, scattering from trees and ground tend to overwhelm the weak backscattering of targets.
2. Target is an object, so are trees. When both of them appear to have similar dielectric and frequency properties, it's hard to make a clear distinction between foliage clutter and desired targets.
3. Due to the changes in atmosphere and ground conditions, foliage is more likely to be a time-variant channel environment. For example, wind results in moving branches and leaves, therefore the foliage clutter is quite impulsive in nature.

There have been many efforts undertaken to investigate foliage penetration (FOPEN). They can be categorized into two groups. One direction is to pursue the foliage clutter modeling and analysis in order to gain better understanding of the clutter and improve the detection performance. Sheen et al. (1994) measured one-way transmission properties of foliage using a bistatic and coherent wide-band system over the band from 300 to 1300 MHz. Fleischman et al. (1996) made measurements of two-way foliage attenuation by synthetic aperture radar (SAR) and discussed probability dependency for frequency, polarization and depression angle. Other than SAR, Millimeter-Wave (MMW) radars also have been applied in measurements of foliage attenuation and ground reflectivity (Schwering et al., 1988; Ulaby et al., 1988; Nashashibi et al., 2004). These studies have showed the strong spatial and angular fluctuations of foliage. The clutter contains many spikes and is very "impulsive", therefore it's difficult to achieve effective and accurate target detection. Although K-distribution has been favored for statistic model of radar clutter (Nohara and Haykin, 1991; Watts, 1987) demonstrated that in very spiky and impulsive foliage clutter, K-distribution is inaccurate. Based on an Ultra-wide band (UWB) radar, (Kapoor et al., 1996) proposed an alpha-stable model while (Liang et al., 2008) presented a log-logistic model for foliage clutter. However, to what extent can the detection performance be improved has not been further analyzed in these studies.

The second group centers on advanced signal processing approaches to support better image formation for target detection. (MacDonald et al., 1997) described the on-going development of a test bed system including real-time UHF FOPEN SAR image formation and Automatic Target Detection and Cueing (ATD/C) processing that was based on Bayesian neural network (BNN) algorithm. However, the BNN discriminator requires an elaborate and extensive training process. Alternative approaches, based on the application of a set of filters, have been proposed. As nonlinear filters have demonstrated good noise suppression characteristics in

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many environments with "spiky noise characteristics, (Mitra et al., 2004) presented a number of simple rank-order filters (Alpha-Trimmed, Modified Nearest Neighbor, Inner-Sigma Filter etc.) for UWB SAR image processing. This work has analyzed that the inner-sigma filter can generate good target detection performance with respect to many of the other filters. Nevertheless, this is very preliminary investigation and further performance estimation is needed. Other interesting filter schemes include adaptive Windrow Least Mean Squares (LMS) filter design (Nanis et al., 1995) and a sequence of directional filters using a hidden Markov model (HMM) (Runkle et al., 2001). Notice that all these approaches are employed for SAR image. Other than SAR, a whitening/dewhitening (WD) transform has been proposed in (Mayer et al., 2003) to help correct target spectral signatures under varying conditions for general multispectral image, but this transform can not be directly applied to colored noise, which also occurs in foliage detection.

Three types of waveforms are commonly seen in the literature dealing with the practical FOPEN measurements. The first type is multiwavelengths. Tan et al. (2007) used multiwavelength Light Detection and Ranging (lidar) to detect a vehicle hidden inside a vegetated area. Due to the fact that a laser beam is generally considered not being able to penetrating vegetation foliage, when the vegetation is dense and the target is completely covered, it is not possible to detect the hidden targets using a lidar sensor. The second type is Millimeter-Wave (MMW) (Nashashibi and Ulaby, 2005), that falls in the class of microwave. Compared to the lidar, the wavelength of microwave is much longer. Microwave and millimeter-wave (MMW) frequencies penetrate through foliage with higher attenuations, and thus this type of radar requires numbers of openings through most foliage covers. Relatively low frequency UWB signals between 100 MHZ and 3 GHz are frequently employed in recent years owning to the following characteristics: (1) high resolutions (2) very good ability of penetration, such as penetrating walls and ground (Ferrell, 1994; Xu and Narayanan, 2001; Withington et al., 2003) 3) low power cost. Despite comparatively short detection range, UWB signal would have advantages over a narrowband signal with limited frequency content.

In this paper, we propose two approaches to detect the target obscured by foliage based on the "good" data (the detail will be provided in Section 2) collected by a UWB radar. One is a differential-based four-step signal processing approach: estimate the clutter decay profile, offset the impulsive clutter, compute the derivative power and finally make a detection decision according to the threshold. The other approach employs short-time Fourier transform (STFT) to distinguish the target from foliage clutter. Both of these approaches provide better detection performance compared to the 2D image algorithm employed in (Withington et al., 2003). As far as "poor" data is concerned, neither differential-based nor STFT approach can detect the target due to the significant pulse-to-pulse variability. In this case, we propose radar sensor network (RSN) and a RAKE structure in addition to the previous signal schemes for data fusion. The numerical performances have been analyzed for both "good" and "poor" data in terms of probability of detection (P_d) and probability of false alarm (P_{fa}).

The remainder of this paper is organized as follows. Section 2 summarizes the measurement of data used in this work. Section 3 proposes differential-based approach and STFT for target detection when the signal quality is "good". Section 4 proposes RSN and RAKE structure when the signal quality is "poor". Section 5 concludes our work and discusses future research.

2. Sense-Through-Foliage data measurement and collection

The sense-through-foliage measurement effort began in August 2005 and continued through December 2005. The data used in this paper were measured in November, involved largely defoliated but dense forest.

The principle pieces of equipment are:

- dual antenna mounting stand,
- two antennas,
- a trihedral reflector target mounted on an artist easel stand,
- Barth pulse source (Barth Electronics, Inc. model 732 GL) for UWB,
- Tektronix model 7704 B oscilloscope,
- rack system,
- HP signal generator,
- IBM laptop,
- Custom RF switch and power supply,
- weather shield (small hut).

A bistatic system (individual transmit and receive antennas) has been used as it was believed that circulators did not exist for wideband signals in 2005. An 18 ft distance between antennas was chosen to reduce the signal coupling between transmitter and the receiver (Henning, 2001). The triangular-shaped target, which was shown in Fig. 1, was a round trip distance of 600 ft from the bistatic antennas (300 ft one way). The UWB pulse generator uses a coaxial reed switch to discharge a charge line for a very fast rise time pulse outputs. The model 732 pulse generator provides pulses of less than 50 picoseconds (ps) rise time, with amplitude from 150 V to greater than 2 kV into any load impedance through a 50 ohm coaxial line. The generator is capable of producing pulses with a minimum width of 750 ps and a maximum of 1×10^{-6} s. This output pulse width is determined by charge line length for rectangular pulses, or by capacitors for 1/e decay pulses.

The radar experiment was constructed on a seven-ton man lift, which had a total lifting capacity of 450 kg. The limit of the lifting capacity was reached during the experiment as essentially the entire measuring apparatus was placed on the lift. It was a 4-wheel drive diesel platform that was driven up and down a graded track 25 m long. The measurement system was moved to different positions on the track. The illustration of the lift was shown in Fig. 2. This picture was taken in September with the foliage largely still present.

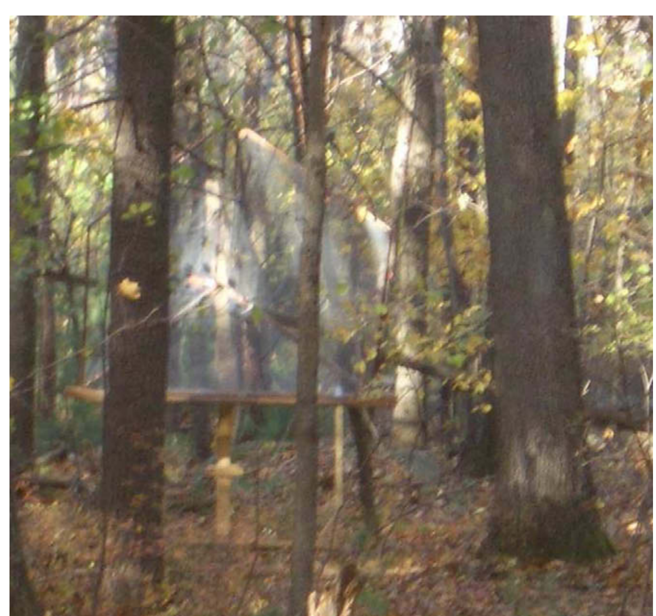

Fig. 1. The target (a trihedral reflector) is shown on the stand at 300 ft from the lift.