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On the Static Clutter Suppression for the DVB-T Based Passive Radars

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Abstract

Passive coherent location (PCL) radars employ non-cooperative transmitters for target detection. The major issues for the PCL radars are the noise presence in the reference signal and the static clutter contribution in the surveillance signal. This paper examines the static clutter suppression methods for the DVB-T based PCL radars. Precisely, it evaluates the impact of the reference signal noise on the existing static clutter suppression methods and it proposes an improved method. Real-data results are employed to demonstrate the proposed method and its efficiency.

1 Introduction

Passive coherent location (PCL) radars employ illuminators of opportunity for target detection and tracking. The illuminators of opportunity can be telecommunication transmitters or broadcasting stations; the most popular ones are GSM, FM, DAB, and DVB-T [1]. The bistatic PCL radars require two receiving channels: a reference channel and a surveillance one. The reference channel receives the direct-path signal from the transmitter of opportunity and the surveillance channel receives the target echo and the static clutter.

The static clutter is formed by the direct-path signal (the largest component of the surveillance signal) and the echoes from the stationary scatterers in the area. The static clutter reduces the detector dynamic range, and its sidelobes mask the weak targets. Thus, a static clutter suppression operation is required to enhance the PCL detection performance [2]. Many static clutter suppression methods have been studied in the literature. Some of them are applicable for all the waveforms like the adaptive filters [2] and the extensive cancellation algorithm (ECA) [3], and others are dedicated for the orthogonal frequency-division multiplexing (OFDM) waveforms like the ECA by carrier (ECA-C) algorithm [4].

The adaptive filters are employed to estimate and suppress the clutter part of the surveillance signal; they use methods like the least mean square filter (LMS). The adaptive filters are computationally heavy and the knowledge of the filter order and the optimal step-size is required to insure an optimum convergence speed [2].

A multistage extensive cancellation algorithm (ECA) has been proposed in [3]; it cancels the masking effect of the clutter sidelobes and the strong target echoes. Firstly, the ECA algorithm eliminates the direct-path signal and the strongest clutter components in the surveillance signal. Then, for each iteration, the strongest peaks in the range-Doppler plane are detected and removed. Once the stopping condition is reached, the processing stops. The ECA algorithm includes matrix inversion operations which increases its computational complexity.

In [4], a static clutter suppression method dedicated to the PCL radars employing OFDM waveforms has been introduced. It is an ECA by carrier (ECA-C) algorithm with a lower complexity than ECA. In the ECA-C, the surveillance signal is divided into a set of carriers taking advantage of the OFDM signal structure, and then the ECA algorithm is applied on each carrier. In [5], an improved version of ECA-C has been introduced, it is named as enhanced cancellation algorithm by carrier and Doppler shift (ECA-CD). The improvement is that ECA-CD allows the removal of the low Doppler clutter.

A low complexity method for static clutter rejection has been proposed in [6]. It is based on the propagation channel estimation in the OFDM signals. It assumes that the propagation channel is invariant over the integration time. The channel estimate is calculated as described for telecommunication systems [7]. The clutter-free signal is obtained by subtracting the propagation channel effect from the surveillance signal. Its results outperform those of the ECA algorithm in terms of low-Doppler targets detection.

The method in [6] employs the least-squares (LS) channel estimation method which is acceptable for telecommunication systems [7]. However, for radar usage, employing an LS channel estimate for the clutter suppression may lead to an important residual clutter in the processed signal. In this work, we propose an improved version of the static suppression technique in [6] and we study the impact of the noise in the reference signal on the static clutter suppression.

The rest of the paper is organized as follows. Section 2 presents the received signal model and the DVB-T signal structure. Section 3 introduces the proposed channel estimation method. In section 4, the reference signal noise

impact on the static clutter suppression is studied. In section 5, we present the real-data results. Section 6 concludes the paper.

2 Signal model

We consider a bistatic passive radar based on the DVB-T illumination as presented in figure 1 and we adopt the signal model employed in [8]. The reference channel receives the reference signal formed by the direct-path signal and corrupted by a thermal noise. The received reference signal x_r is expressed as

$$x_r(n) = \beta s(n) + v(n), \tag{1}$$

where $s(n)$ is the DVB-T signal transmitted by the broadcaster with a variance σ_s^2, β is a scaling parameter representing the propagation losses and the antenna gain, and $v(n)$ is a complex Gaussian noise with zero mean and variance σ_v^2. We define the signal-to-noise ratio of the reference signal as $SNR_r = |\beta|^2\sigma_s^2/\sigma_v^2$.

The surveillance signal is formed by a set of static clutter echoes resulting from the static scatterers in the surveillance area, a thermal noise and a possible target echo. We adopt the following model for the surveillance signal

$$x_s(n) = \sum_{l=0}^{L-1} h_l s(n-l) + \alpha s(n-\tau)e^{j2\pi f_d n} + w(n), \tag{2}$$

we considered L scatterers with time-invariant reflection coefficients h_l. The thermal noise $w(n)$ has a zero mean and a variance of σ_w^2. The target echo is characterized by τ the time-delay, f_d the Doppler frequency and the coefficient α that expresses the target reflectivity and the propagation losses which is assumed to be constant during the integration time. The clutter-to-noise ratio (CNR) of the surveillance signal is defined as $CNR = \sum_{l=0}^{L-1} |h_l|^2\sigma_s^2/\sigma_w^2$.

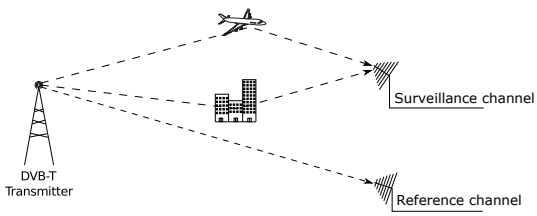

Figure 1. Passive bistatic radar configuration.

The orthogonal frequency division multiplexing (OFDM) modulation scheme is employed in the DVB-T standard where K orthogonal subcarriers are utilized to form one DVB-T symbol [9]. For one DVB-T symbol, the signal $s(n)$ is formed as follows

$$s(n) = \sum_{k=0}^{K-1} c_k e^{j2\pi f_k n}, \tag{3}$$

with K is the number of subcarriers, f_k is the frequency of the kth subcarrier and c_k are the complex-valued quadrature amplitude modulation (QAM) symbols. Figure 2 shows the DVB-T frame structure. Among the K subcarriers, there are K_d data subcarriers and K_p pilot subcarriers. The data subcarriers convey video coded information and the pilot subcarriers are used for signal synchronization and propagation channel estimation.

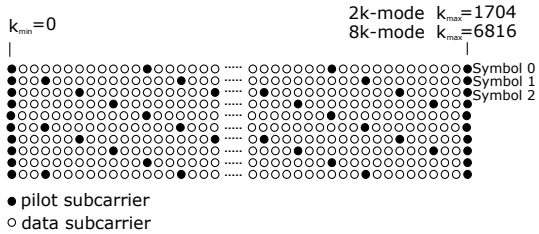

Figure 2. DVB-T frame structure.

3 Proposed channel estimation method

The static clutter suppression method presented in [6] employs the least squares (LS) method for the channel estimation. For the LS channel estimation method, the surveillance signal is divided into DVB-T symbols. For each symbol, the cyclic prefix is removed and an FFT is applied; for each subcarrier, the result can be expressed as

$$X_s(k) = H(k)c_k + X_t(k) + W(k), \tag{4}$$

where $H(k)$ is the channel weight for the kth subcarrier, $X_t(k)$ is the target echo contribution and W is the FFT of the noise w. We neglect the target component in the surveillance signal since $h_l \gg \alpha$. Since the pilot subcarrier amplitudes are known, an estimate of the channel response can be calculated for pilot subcarriers as follows

$$\hat{H}(p) = X_s(p)/c_p, \tag{5}$$

where p is the pilot subcarrier index. The full channel response, $\hat{H}$, is obtained by interpolating the channel response at the pilot subcarriers. An averaging of the channel estimates over M DVB-T symbols reduces the noise impact on the estimation [6]. The clutter-free component for the kth subcarrier is obtained as follows

$$X_{filtered}(k) = X_s(k) - \hat{H}\hat{c}_k, \tag{6}$$

where $\hat{c}_k$ are the QAM symbols obtained from the reference signal reconstruction [1]. the time-domain filtered signal is obtained by applying an IFFT on the filtered subcarriers $X_{filtered}$.

The channel estimate is affected by the interpolation errors since the channel response is interpolated between pilot subcarriers which are spaced by 12 ΔF with ΔF is the subcarrier spacing. Thus, a reduction of the interpolation errors can improve the channel estimation accuracy. As shown in figure 2, the pilot subcarrier distribution is periodic with a period of four DVB-T symbols. For each period, there are four overlapping pilot patterns. To reduce the interpolation error, we propose to calculate the averaged channel

response for each pilot pattern. The concatenation of the four patterns reduces the interpolation gap to 3 ΔF.

Figure 3 presents the normalized mean-square error (NSME) for the LS channel estimator and the proposed one. We notice that the proposed method provides an accurate channel estimate compared to the LS method due to the interpolation error reduction.

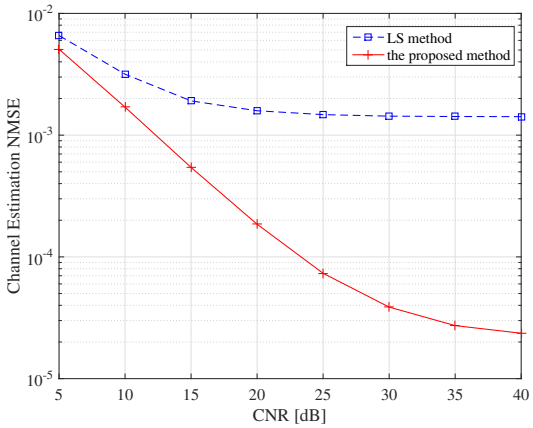

Figure 3. Normalized mean-square error for the channel estimation methods.

4 Impact of the Reference signal noise on the static clutter suppression

In a realistic scenario for the PCL radars, the reference and surveillance signals are often corrupted by noise and static clutter, respectively. In [8, 10], the impact of the reference signal noise on the detection performance has been addressed. The direct-path signal presence in the surveillance signal reduces significantly the detection probability for PCL radars as described in [8]. This finding can be generalized to include the rest of the static clutter components. Thus, a clutter removal process is required to enhance the detection probability.

The existing static suppression methods require a noise-free reference signal to achieve a full static removal. However, the realistic scenarios are not conform to this requirement. This section investigates the impact of the reference signal noise on the static clutter suppression process for DVB-T based PCL radars, which will provide an insight about its efficiency in the realistic scenarios.

In figure 4, we compare the zero-range cut in the range-Doppler diagram for different static clutter suppression methods employing simulation data. The first case represents the cross-correlation output without static suppression. In the second case, an LMS filter is applied employing a noisy reference signal ($SNR_r = 15dB$). For the third case, a reconstructed reference signal is employed for the LMS filter. In the fourth case, we employed the method in [6]. The fifth case presents the results of the proposed method. We clearly notice the efficiency loss of the LMS filter for the noisy reference signal case. Even for a reconstructed reference signal, the static clutter was not fully suppressed. In fact, with an $SNR_r = 15dB$, the reconstruction noise is significant in the reconstructed signal. The method in [6] achieved an efficient clutter suppression except the remaining direct-path signal (at zero-Doppler). The proposed method fully suppressed the static clutter thanks to the improved channel estimation method.

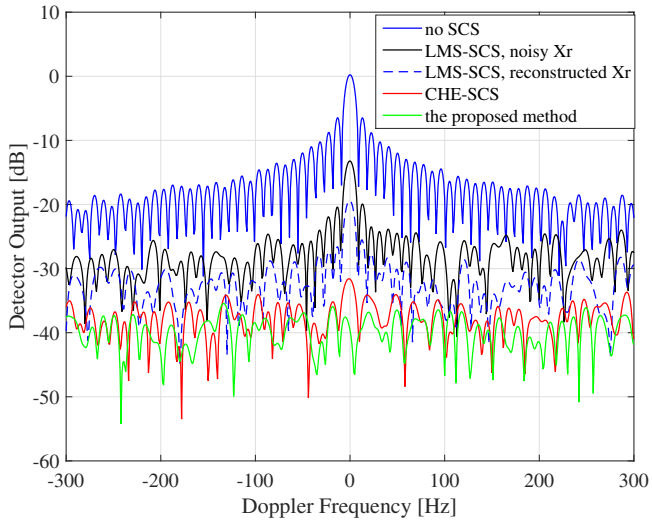

Figure 4. Detector output for different static clutter suppression (SCS) methods. x_r: reference signal, CHE: channel estimation method.

5 Real data results

The measurement campaign took place in Brussels at the Royal Military Academy. The illuminator of opportunity is located on the top of the Finance Tower. The DVB-T broadcaster emits at a central frequency of 484 MHz employing the $8k-mode$ with a guard interval $GI = 1/4$ and a radiated power of 10 kW. The nearby Zaventem airport offers the opportunity of having low altitude targets.

Figure 5 shows the detected path of an airplane employing the method in [6], and figure 6 presents the results employing the proposed channel estimation method for the reference signal reconstruction and for the static clutter suppression. The results are produced by the summation of 100 range-Doppler diagrams. For each range-Doppler diagram, we employed an integration time of 0.1 s which is equivalent to $N = 10^6$ time samples. We can notice that the proposed approach allowed a larger range cover than the LS one, this is due to the accuracy of channel estimation which led to an efficient reference signal reconstruction, and thus, a higher integration gain. Figure 7 shows a 1D cut on the previous results at the target range. For the LS channel estimate case, we can notice the remaining peak around zero-Doppler which marks the inefficiency of the clutter removal due to the inaccuracy of the channel estimation. At the target-Doppler ($f_d = -85Hz$), the integration loss for the LS case (compared to the proposed method) is due to the use of the LS method for reference signal reconstruction.

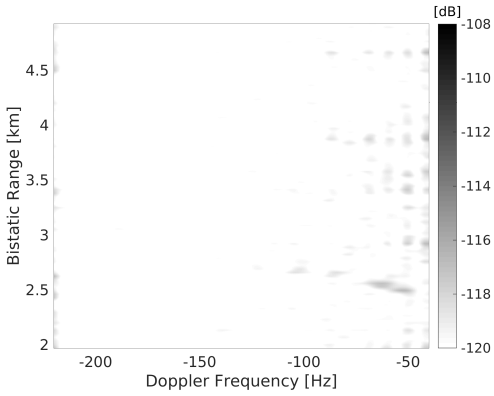

Figure 5. Real data detection result for one target path using LS method for channel estimation.

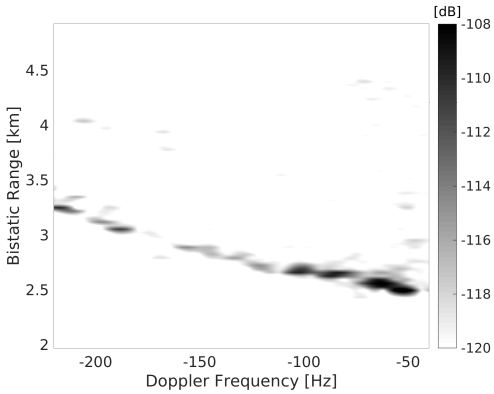

Figure 6. Real data detection result for one target path using the proposed channel estimation method.

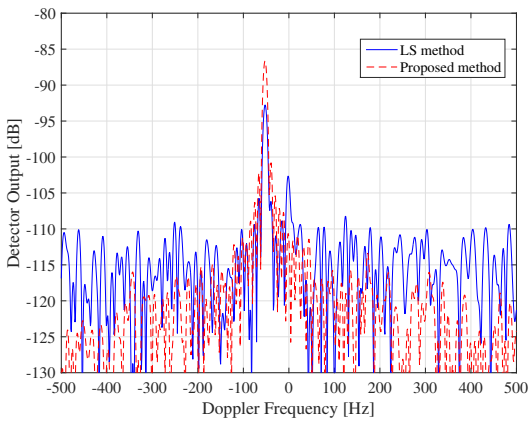

Figure 7. Real data detection result for one target.

6 Conclusion

The reference signal noise degrades the static clutter suppression performance since the conventional static clutter suppression methods require a noise-free reference to operate precisely. An accurate estimate of the propagation channel can replace the conventional methods for clutter suppression and overcomes the issues due to the reference signal noise. The real-data results showed the efficiency of the proposed method in an urban area with a strong fading and a single frequency network (SFN) influence. Other channel estimation methods will be considered in the future work including SVD and MMSE methods. The final paper will include more details about the present work.

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