Improved Detection for Passive Radar by Illumination Matching on Reference Channel

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Abstract: *A novel technique for enhancing the detection of targets of interest is presented for application on the context of passive radar. The methodology is inspired on the well known Matched Illumination technique used in active systems and applies to scenarios where the targets can be modeled as having a few predominant scatterers. Since passive systems have no control over the signals which are transmitted by the illuminators of opportunity, the paper proposes to match the signal received on the reference channel. Results show that the correlation function will be enhanced for the targets of interest, relatively to the remaining targets and the clutter on the target region.*

1. Introduction

A passive radar system does not have its own dedicated transmitter; instead, it uses an illuminator of opportunity to detect targets and estimate their kinematic parameters [1].

The basic idea is to measure the differences between the signal directly received from the illuminator of opporunity and the signal reflected on the objects on the target area.

This concept is not new, with first documented experiments in 1935 by Robert Watson-Watt who was able to demonstrate the principle by detecting a bomber using the BBC shortwave transmitter as illuminator of opportunity.

Since passive radar does use the signals from transmitters which are already available on the region of interest it is can be much cheaper than an active system. Moreover, and maybe more important for military activities, it can work in covert mode.

The sources of illumination can be quite different. More conventional ones include enemy's own active radars or broadcast FM and digital TV already illuminating the area of interest.

More recently, passive systems using signals from low power space-based illuminators such as DVB-S [2], or even GNSS [N3] have been presented.

The conventional acquisition geometry and processing chain for passive bistatic radar is depicted in Fig. 1. in which a broadcast transmitter is used as illuminator of opportunity.

The so-called reference channel acquires the signal directly received from the transmitter of opportunity. The so-called surveillance channel acquires the signal that is scattered by the objects in the target area.

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The basic principle consists in computing the cross-correlation between the signal on the reference channel and the signal on the surveillance channel.

However there is a serious limitation in range detection that is imposed by the signal-to-interference ratio due to the strong signal directly received on the surveillance channel. Tipically this limitation can be tackled with adaptive cancellation based on adaptive filtering [5].

Only after the adaptive cancellation one can perform the cross-correlation between the signals, which is typically followed by a constant false alarm rate (CFAR) module [5] as shown in Figure 1.

2. Target Detection

Target detection in a passive radar is strongly dependent on the cross-correlation between the surveillance signal, $s_s(t)$, and the reference signal, $s_r(t)$.

In order to produce a range-velocity map, the correlation is made with several shifted replicas of the reference signal [6].

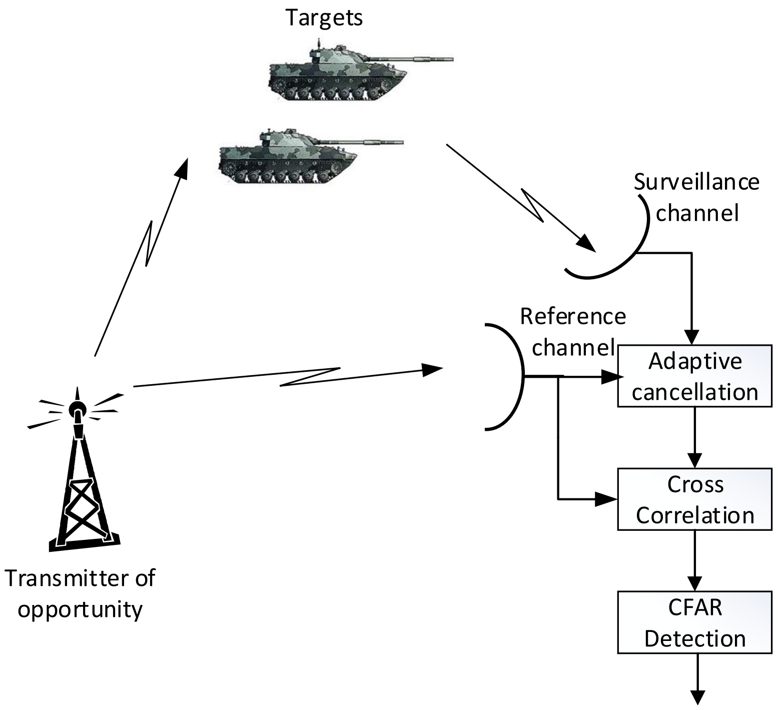

Figure 1. Passive radar bistatic acquisition geometry and typical processing chain.

The range-velocity map is computed by

$$C(\tau, v) = \left|\int_{-\infty}^{+\infty} s_r(t) s_s^*(t-\tau) \exp(j2\pi f_d t)\, dt\right| \qquad (1)$$

where τ is related with the range by

$$\tau = 2rc,$$

v is the target velocity projected in the line of sight (LOS) of the receiver, and the frequency Doppler shift induced by the moving target is given by

$$f_d = \frac{2v}{\lambda}.$$

This paper addresses the scenario where the purpose is to detect man-made targets which can be modeled as the sum of a few predominant scatterers [7]. In this context, there are some optimizations that can be done.

A possible optimization consists in using the matched illumination technique which is applied in active radars. Such an example is published in [8], where the author suggests modifying the emitted noise signal making it a composite noise waveform consisting of appropriately summed delays of the original signal to be transmitted. The rationale behind this is that if the arrangement of scattering centers exactly matches that of the transmit waveform, the correlation function will also be enhanced due to the summation of correlations at the individual delays.

The major drawback with the proposed technique is that the received echoes from the target scene are optimized for the targets of interest and will not be useful for other purposes such as offline processing for recognition of secondary targets.

To circumvent this limitation, an alternative methodology has recently been proposed, by this author, in which the original waveform is transmitted without any modification [9]. Instead, it is the reference signal that is modified using a composition of sums and delays of the original waveform matching those of the target of interest. This will be the signal used as reference for correlation with the received echoes from the target area.
This way the detection of targets of interest will be enhanced and the received data will still be useful for other purposes since there are no modifications to the emitted noise signal.

The present paper elaborates on the idea presented in [9] and [10], with small modifications, to make it suitable for application on passive radar systems as described in the following sections.

3. Matched Illumination on Reference Channel

In passive radar one cannot change or influence the signals generated by the transmitters of opportunity. However, the signal received on the reference channel can be matched, similarly to what is proposed in [9], to the targets of interest.

The technique is illustrated in Fig. 2 and can be applied if the desired targets can be modeled as the sum of a few predominant scatterers.

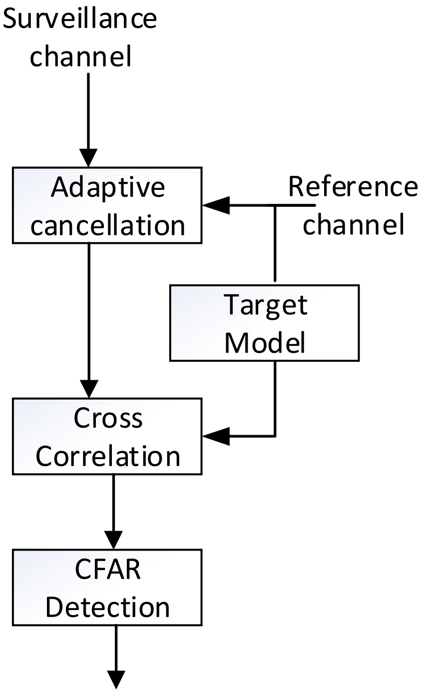

Figure 2. Proposed match on reference illumination on passive radar.

The basic principle consists in matching the signal received on the reference channel using the knowledge that the returned echo from the target of interest will be, approximately, a sum of replicas of the signal emitted by the transmitter of opportunity, delayed and weighted by each of the scatterers position and reflectivity.

Therefore, the reference signal can be modified in accordance to

$$m(t) = \sum_{i=0}^{p-1} \frac{1}{p} r(t - t_i), \qquad (2)$$

where p is the number of predominant scatterers, and $r(t - t_i)$ is the appropriately delayed version of the signal on the reference channel.

Signal $m(t)$ will be used as reference for correlation with the received echoes from the target area, as illustrated in Fig. 2. This way the correlation will exhibit a single and stronger peak, enhancing the detection of targets of interest that will be computed by the CFAR module.

This simple model can be implemented in software or in hardware through coaxial cable and power divider/combiner as illustrated in Figure 3.

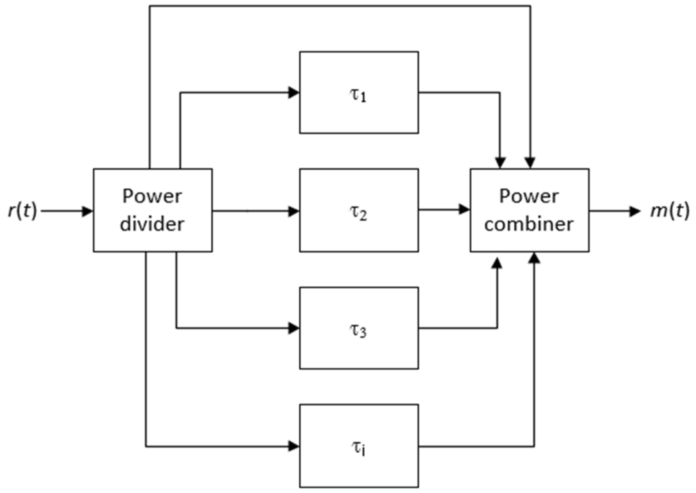

Figure 3. Target model block diagram.

4. Results

This section present simulation results to illustrate the detection gains obtained by matching the signal on the reference channel.

The parameters for the illuminator of opportunity are listed in Table 1.

The simulations consider the presence of 12 targets, belonging to 2 classes: C1 and C2. For illustration purposes only, all the targets have the same RCS and are modelled as having 3 main scatterers. However, the main scatterers relative position are different for targets of class C1 when compared with those of class C2.

The target parameters are summarized on Table 2.

Parameter	Value
Carrier frequency	860MHz
BW	8MHz
Sampling frequency	30MHz

Table 1: Parameters of transmitter of opportunity.

Target	Class	Range	Doppler
1	1	960	$-3\pi/4$
2	1	960	$\pi/2$
3	1	1600	$\pi/4$
4	1	2880	$3\pi/4$
5	1	3000	0
6	1	3100	$-\pi/2$
7	1	3520	$-\pi/4$
8	2	640	$3\pi/4$
9	2	1280	$\pi/4$
10	2	1920	0
11	2	2560	$-3\pi/4$
12	2	3200	$-\pi/4$

Table 2: **T**argets on the scene.

Figure 4 presents the resulting intensity image from the computation of (1). As expected, all the 12 targets produce peaks of similar amplitude.

After applying the model (2) of the desired targets, i.e. targets of type 2, and computing (1), the resulting peaks are quite different between the two types of targets.

As predicted, the undesired targets have been attenuated, comparatively to the previous results and, in contrast, the correlation for the targets of interest is now enhanced, showing a single peak as illustrated by Fig. 5.

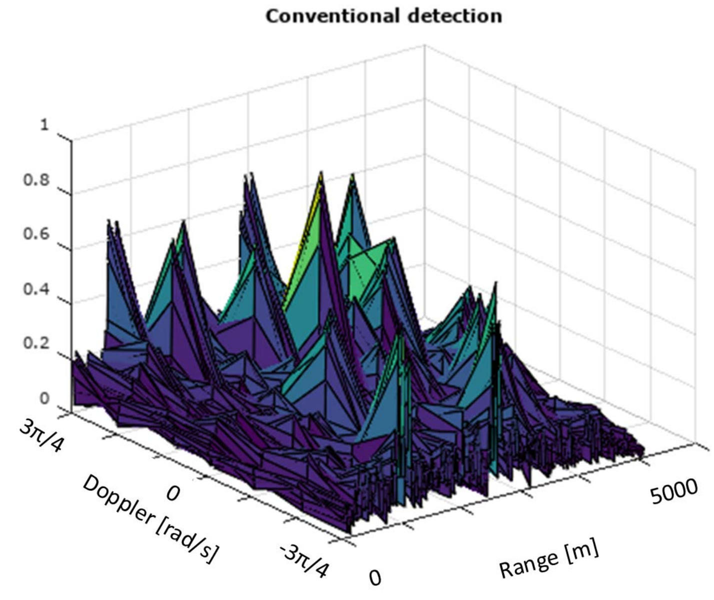
Conventional detection

Figure 4: Conventional detection where all the 12 objects appear in the target region.

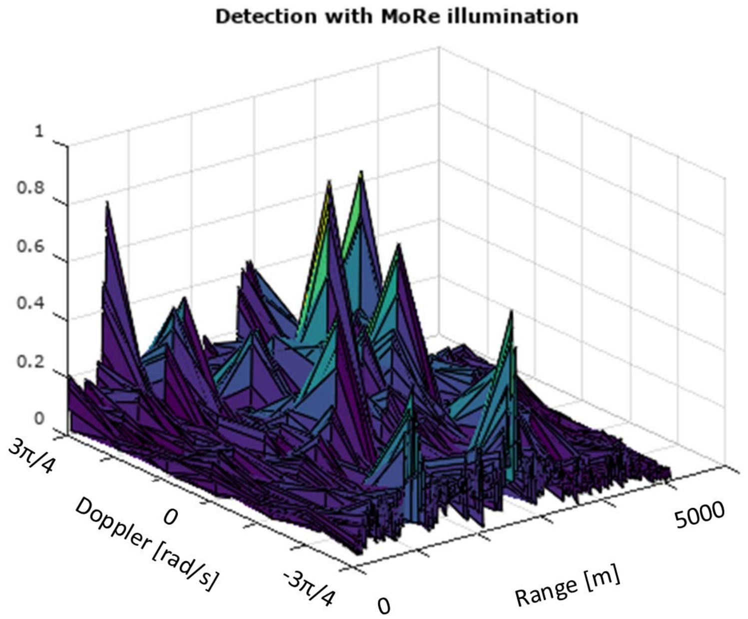

Figure 5: Using the matched illumination on reference channel leads to the attenuation of the C1targets and to the enhancement of the C2 targets detectability.

Fig. 6 presents the result from conventional detection for targets with velocity inducing a Doppler shift of $\frac{3}{4}\pi$ [rad/sample]. As expected, only two clusters of peaks appear, belonging to targets 4 and 8, both with similar maxima since the targets have the same RCS.

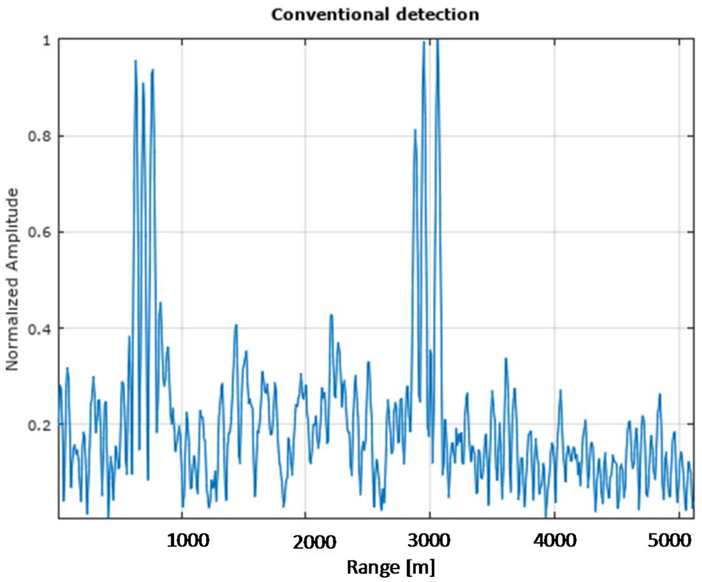

Figure 6: Conventional detection for yargets inducing Doppler shift of $\frac{3}{4}\pi$ [rad/sample].

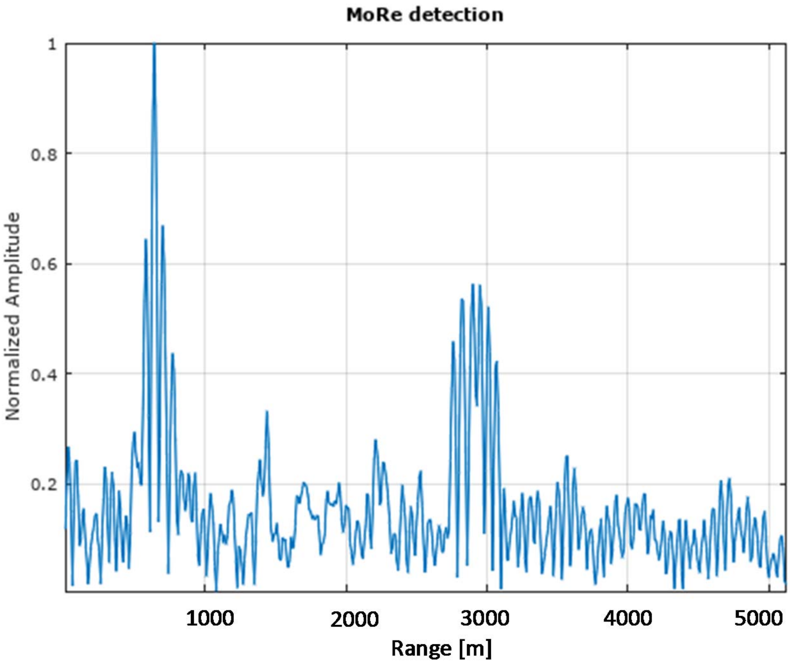

Figure 7: Match on reference (MoRe) detection: Target of the desired class becomes predominant.

Fig. 7 presents the result from match on reference (MoRe) detection for targets with velocity inducing a doppler shift of $\frac{3}{4}\pi$ [rad/sample]. Although two clusters of peaks appear, only one is predominant, almost doubling the amplitude of the other. Moreover, the predominant cluster is *focused* into a single peak, whereas the second cluster, when compared with that from Fig. 6 has become spreaded.

5. Conclusions

A novel technique for enhancing the detection of targets in the context of passive radar has been presented. The technique applies to targets that can be modelled has having a few predominant scatterers, which correspond to many situations involving man-made objects.

The technique is inspired on the Matched Illumination tipically applied for active systems. However, since passive systems have no control over the illumination signals, the matching is done on the signal received in the surveillance channel.

Simulation results are encouraging, showing a detection improvement for the targets of interest while, simultaneously, reducing the contribution from the remaining targets and clutter on the target area.

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