Detection of manoeuvring low SNR objects in receiver arrays

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Introduction

We are interested in detection of low signal to noise ratio (SNR) and manoeuvring objects, which is a challenging task in wide area surveillance applications.

We propose a joint long time integration and trajectory estimation algorithm for a uniform linear array (ULA) receiver.

• This approach facilitates long time integration and performs coherent integration within a CPI and non-coherent integration across consecutive CPIs along the object trajectory.

• The object trajectory is used to adapt the observation environment to allow for a gain in SNR.

We use Bayesian recursive filtering (see, e.g., [4]) for estimation of the object trajectory \( \mathbf{x}_k \) and a maximum likelihood estimator for estimation of the reflectivity coefficients \( \mathbf{A}_k \).

Problem Statement

• We consider a scenario in which a transmitter emits \( N \) pulses separated by \( T \) seconds towards a surveillance region (Fig. 1).

• A uniform linear array (ULA) receiver (red dots) collects reflected versions of the transmitted pulses.

• The reflections are characterised by the object kinematics \( \mathbf{x} = [x, y, \dot{x}, \ddot{y}] \) and a complex reflection coefficient.

• Conventional coherent and non-coherent integration consider range-bearing and doppler bins, and, perform integration for the same bins without taking into account the possibility of object manoeuvres across them [1, Chp.6].

• This leads to failure in collecting all the evidence for testing the object existence hypothesis contained in the received signal as illustrated in Fig. 2.

Radar measurements over time

![Detection of manoeuvring low SNR objects](https://example.com/detection.png)

**Fig. 1.** Illustration of the problem scenario: A transmitter (a red triangle) and a ULA (red dots) collect low SNR measurements from an object at location \( [x, y] \) with velocity \( [\dot{x}, \ddot{y}] \).

**Fig. 2.** Detection using conventional methods of non-coherent (green solid line) and coherent (black solid line) integration in comparison with a detection threshold (magenta solid line) for a given constant false alarm rate (CFAR).

The proposed detection algorithm

Our Contribution:

• We designed a joint pulse integration and trajectory estimation algorithm, which allows us to detect a low SNR object by integrating the reflection coefficients along the object trajectory.

• We use a Neyman-Pearson test [3] given the object trajectory \( \mathbf{x}_k \) and the complex reflection coefficients \( \mathbf{A}_k \):

\[
L_{1,1}(\mathbf{Z}_k | \mathbf{I}_k) \propto \sum_{k=1}^{K} \left| \mathbf{I}_k \mathbf{I}_k^H + \mathbf{H}_k \right|^{-1} \mathbf{H}_k^H \mathbf{H}_k
\]

• The detection threshold \( \mathcal{T}_p \) is specified for a given CFAR.

**Example:**

Table 1. Transmitted signal parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency ( f_c )</td>
<td>10GHz</td>
</tr>
<tr>
<td>Bandwidth ( B )</td>
<td>1MHz</td>
</tr>
<tr>
<td>Pulse repetition interval ( T )</td>
<td>100us</td>
</tr>
</tbody>
</table>

**Fig. 3.** Block diagram of the proposed detector: (a) the Markov model for the measurements and (b) inference on the object trajectory \( \mathbf{x}_k \).

**Fig. 4.** (a) Long time integration with the proposed algorithm, (b) Probability of detection versus time. All for an \(-2\)dB SNR object results averaged over 100 Monte Carlo simulations.

• The integrated energy using the proposed integration (blue solid line in Fig. 4(a)) is close to the best achievable integration using the full knowledge of the true trajectory.

• The proposed integration allows us to detect the object after \( t = 3.48s \).

• The \( P_d \) for the proposed approach (blue solid line in Fig. 4(b)) reaches almost 1 by \( t = 7s \), which is similar to the \( P_d \) using the true trajectory (red dash line), whereas conventional coherent and non-coherent integration fail to detect.

Conclusion and Future work

• The proposed algorithm performs long time integration with an accuracy close to the best achievable integration with the full knowledge of the true trajectory.

• Our future work includes further experimentation for the characterisation of the algorithm under different SNR working condition, and, adaptation of this approach in distributed multiple radar applications.

Acknowledgement:

This work was supported by the Engineering and Physical Sciences Research Council (EPSRC) grants EP/K011580/1 and EP/K014277/1, and the MOD University Defence Research Collaboration (UDRC) in Signal Processing.

Reference:


