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 algorithm allows us to detect a low SNR object by integrating multiple pulse returns while taking into account the object manoeuvres.
- This approach involves estimation of the object trajectory, and, complex reflection coefficients and evaluates a likelihood ratio test related to the reflected pulse energy.
- The ULA structure (e.g., [2]) allows us to estimate complex reflection coefficients with favourable accuracy using the limited amount of data available in a coherent processing interval (CPI).
- This approach results in an integrated value close to the best achievable using the full knowledge of the true trajectory.

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 $X = [x, y, \dot{x}, \dot{y}]^T$ and a complex reflection coefficient.

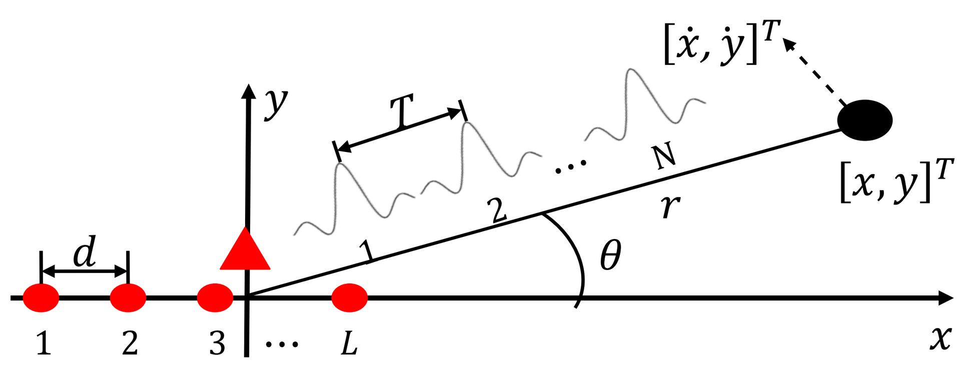

Fig. 1. Illustration of the problem scenario: A transmitter (a red triangle) and a ULA (red dots) collect low SNR measurements from an object at location $[x, y]^T$ with velocity $[\dot{x}, \dot{y}]^T$

- 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 manoeuvers 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.

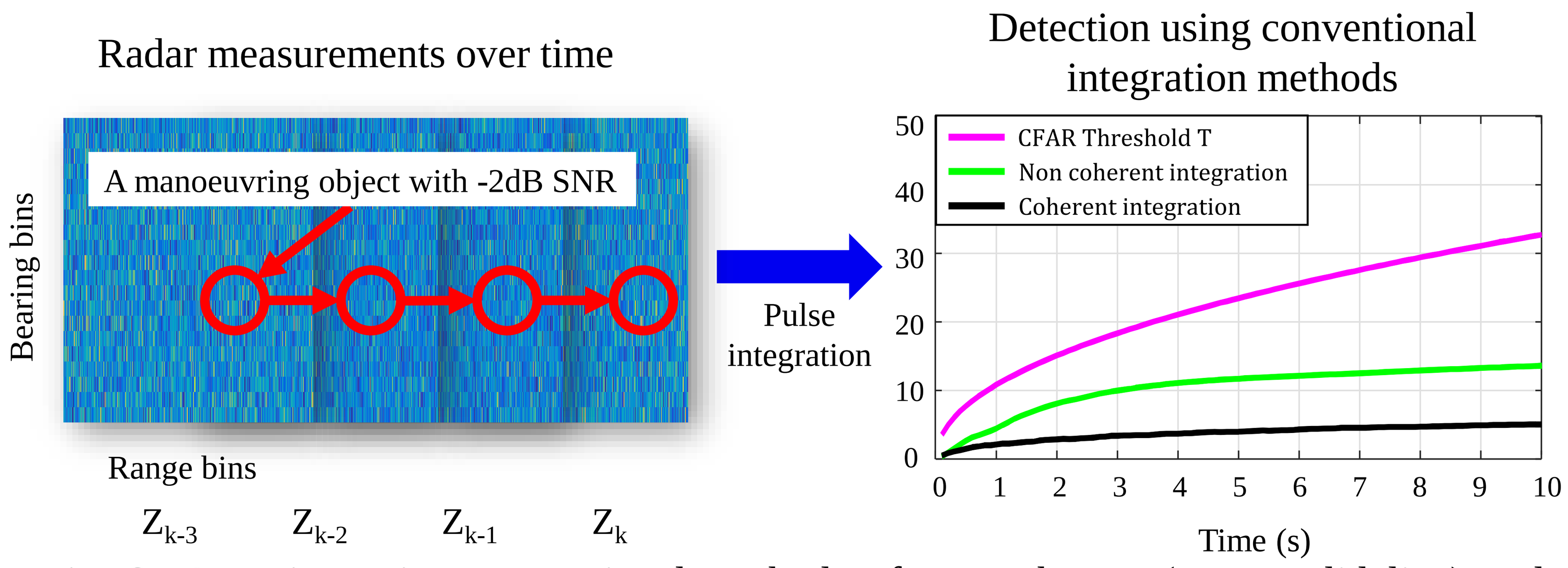

Fig. 2. Detection using conventional methods of non-coherent (green solid line) and coherent (black solid line) integration in comparison with a detection threshold (magenta solid line) for a given constant false alarm rate (CFAR).

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 $X_{1:K}$ and the complex reflection coefficients $A_{1:K}$:

$$L_{1:K}(Z_{1:K}(i_{1:K})|X_{1:K}, A_{1:K}) = \prod_{k=1}^{K} \frac{l(Z_k(i_k)|X_k, A_k, H_1)}{l(Z_k(i_k)|\, H_0)} \underset{H_0}{\overset{H_1}{\gtrless}} \mathcal{T}_K$$

- The detection threshold $\mathcal{T}_K$ is specified for a given CFAR.

- We use Bayesian recursive filtering (see, e.g., [4]) for estimation of the object trajectory $X_{1:K}$ and a maximum likelihood estimator for estimation of the reflection coefficients $A_{1:K}$.
- This approach facilitates long time integration and performs coherent integration within a CPI and non-coherent integration across consecutive CPIs along the object trajectory.

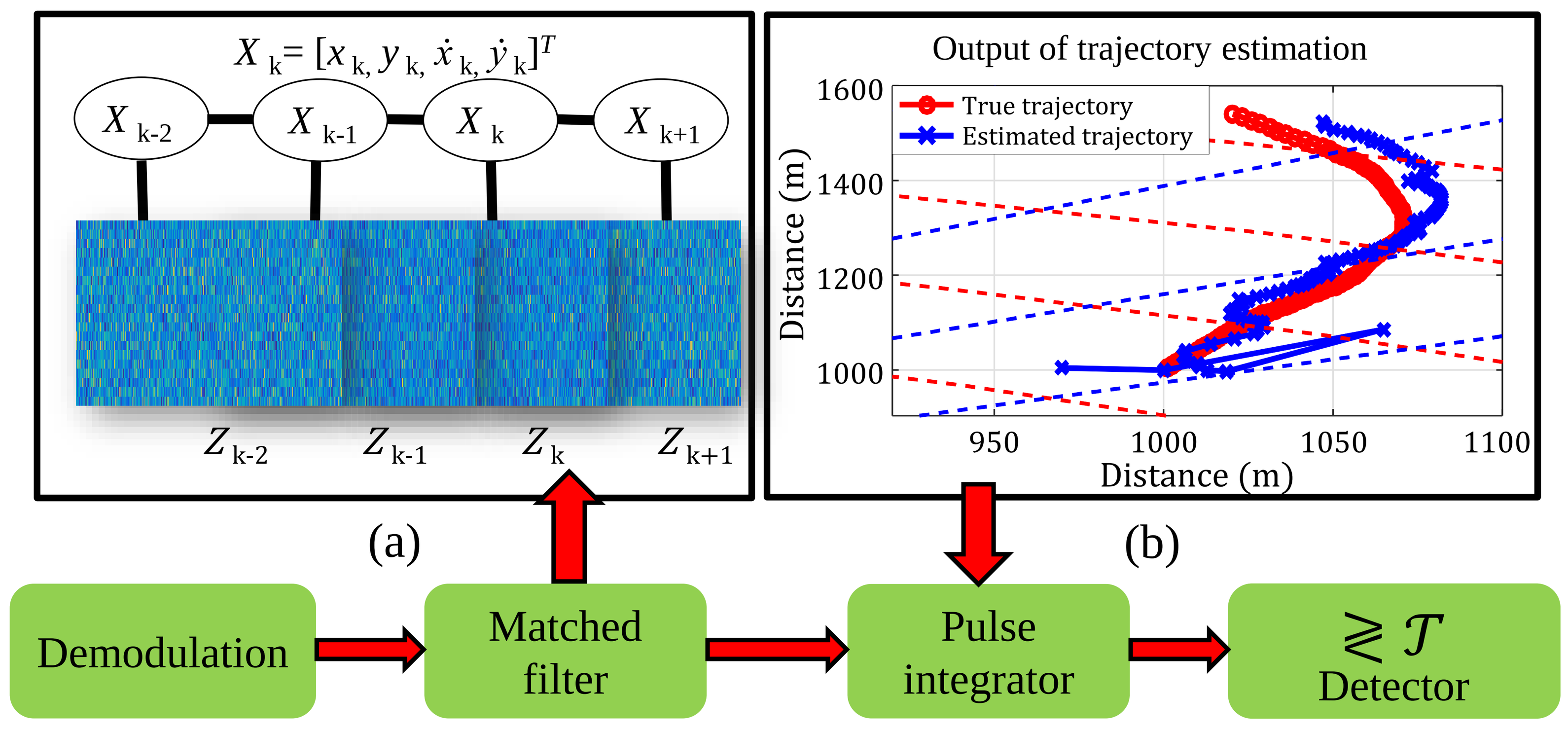

Fig. 3. Block diagram of the proposed detector: (a) the Markov model for the measurements and (b) inference on the object trajectory $X_{1:K}$

Example:

Table.1. Transmitted signal parameters.

Parameter	Value	Parameter	Value
Carrier frequency f_c	10GHz	Coherent processing interval (CPI)	0.1s
Bandwidth B	1MHz	Number of pulses in a CPI N	20
Pulse repetition T	100us	Number of elements in ULA L	20

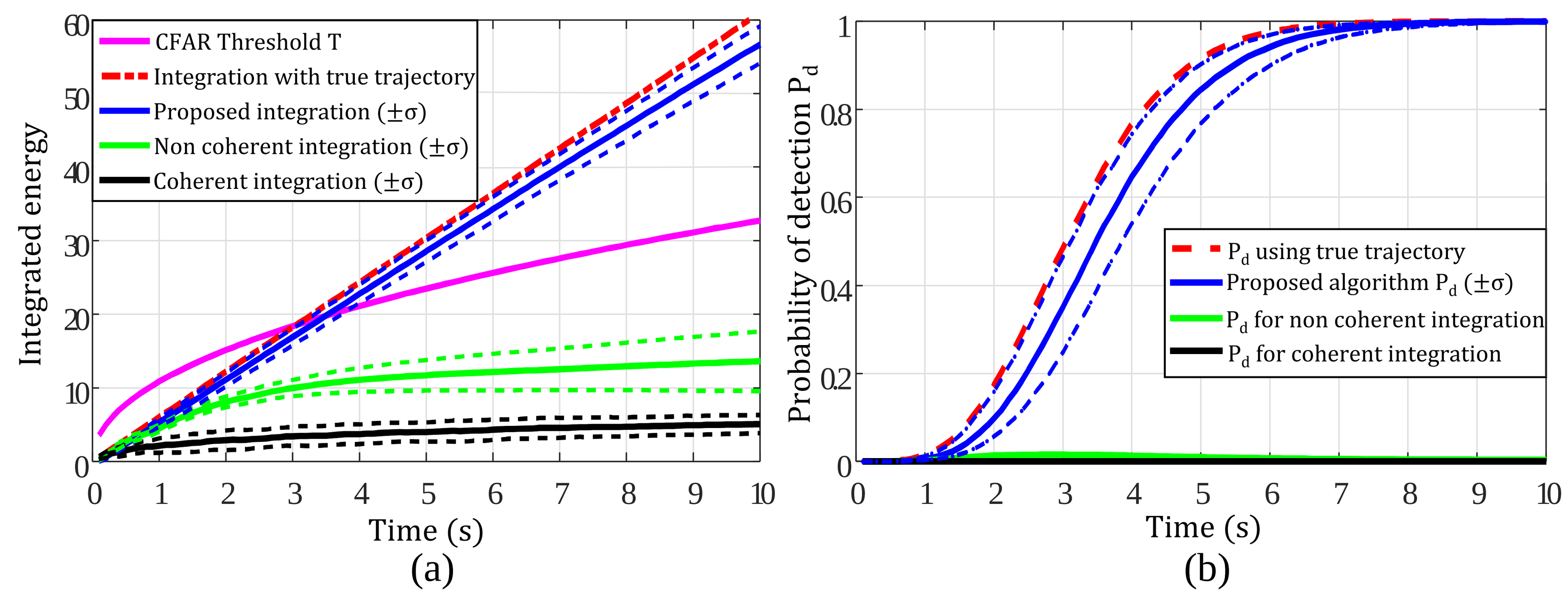

Fig. 4. (a) Long time integration with the proposed algorithm, (b) Probability of detection versus time, All for an -2dB SNR object results averaged over 100 Monte Carlo simulations.

- 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/J015180/1 and EP/K014277/1. and the MOD University Defence Research Collaboration (UDRC) in Signal processing.

Reference:

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This work was supported by the Engineering and Physical Sciences Research Council (EPSRC) and Dstl