A Multi-Model Track-before-Detect Algorithm for Manoeuvring Target Detection for Over-the-Horizon Radar

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***Abstract*— In this paper a multi-model track-before-detect (MM-TBD) is proposed for the HF Over-The-Horizon-Radar (OTHR) manoeuvring target detection. Multiple hypotheses about target manoeuvres and echo sources are represented in the multi-model-estimation framework with each sub-filter corresponding to one hypothesis. The track output of each sub-filter is obtained based on the maximum likelihood criterion and then a generalized likelihood ratio for hypothesis test is presented to target detection. A numerical simulation is presented to show the effectiveness of the proposed algorithm.**

I. INTRODUCTION

High Frequency Over-The-Horizon Radar (HF-OTHR) is widely used for wide-area surveillance and long-range tracking of aircrafts and ships [1]. To get more transmitting power, frequency modulated-continuous waveform is mostly adopted. The usual processing for echo signals includes beamforming, pulse compressing and coherent integration. And then the CFAR detection is utilized to examine the existence of the targets at each range-azimuth cell. This performs well when the target's velocity is constant and the signal-to-noise ratio (SNR) is high. The low SNR target or manoeuvring target, however, is hard to be detected. For a manoeuvring target, the non-zero radial acceleration makes the phase of the echo signal nonlinear, which leads to the spectral spread and energy dispersal when FFT is used in coherent integration. As a result, the Doppler resolution and coherent integration performance are degraded [2].

There have been several works on low SNR or manoeuvring target detection for OTHR. G. Wang et al. proposed an adaptive chirplet transform based method [2]. Lu Kun [3] presented an algorithm based on high-order ambiguity function via a high-order polynomial representation of the phase of echo signals, and then a process of estimation and compensation of high-order radial motion components was made for improving the coherent integration performance. Su Hongtao [4] proposed a particle filter based track-before-detect (TBD) algorithm for OTHR manoeuvring target detection. The author in [5] proposed a TBD method for detecting low SNR and constant velocity target with short coherent integration time (CIT) by accumulating a posterior probability across multiple dwells prior to detection.

In this paper, a multi-model track-before-detect (MM-TBD) algorithm is proposed for OTHR. It can detect the time when the manoeuvre occurs and estimate the radial velocity and acceleration of one target. A numerical simulation is given to testify the proposed method.

II. MULTI-MODEL STRUCTURE

The multi-model idea has been widely used in the estimation of hybrid systems. Assume there are r models $\Pi = \{\pi^{(j)}\}_{j=1,\cdots,r}$, and each model $\pi^{(j)}$ corresponds to one mode in the mode space. The constant velocity (CV) model and constant acceleration (CA) model are considered in this paper. The corresponding relationship between target state $\boldsymbol{x}^{(j)}$ and it's mode in the k^{th} dwell is as follows.

$$\pi_k^{(j)} \triangleq \left\{ \boldsymbol{x}_k^{(j)} \Leftrightarrow \pi^{(j)} \right\}, \quad k = 1, \cdots K, \ j = 1, \cdots, r \tag{1}$$

To the problem of the manoeuvring target detection for OTHR, since the typical range resolution of an OTHR is about $10km$, we assume the target cannot travel across one range bin during several CITs, only the velocity and the acceleration are involved in the target state $\boldsymbol{x}^{(j)}$.

A. CV Model

When a target moves with a constant velocity, the target state variable, corresponding to the mode $\pi^{(1)}$ at the k^{th} dwell, can be defined as the Doppler frequency $f_{v,k}$ according to the relationship $f_{v,k} = 2v_k/\lambda$, where v_k is the radial velocity and λ is radar operating wavelength.

$$\boldsymbol{x}_k^{(1)} = f_{v,k} \tag{2}$$

And the target CV model can be described as

$$\pi^{(1)}\text{:} \ \boldsymbol{x}_k^{(1)} = \boldsymbol{x}_{k-1}^{(1)} + \xi_{k-1} \tag{3}$$

Where $\xi_{k-1} \sim N(0, \sigma_{f_v}^2)$ is a zero-mean white Gaussian process with variance $\sigma_{f_v}^2$. It represents a slight random change of target Doppler between dwells.

B. CA Model

Consider a target with an initial velocity v_k and an acceleration a_k in the radial direction at the k^{th} dwell, the target state, corresponding to the mode $\pi^{(2)}$, is defined as