Detection of Dim Maneuvering Target Ased on Randomized Hough Transform

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Abstract

This paper presents a method of applying the randomized Hough transform to detect dim maneuvering targets in noise. Using the randomized Hough transform, the power of dim maneuvering targets can be integrated in the transformed Hough space wherein the targets are detected. The effectiveness of this technique is demonstrated under several simulation scenarios.

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1. Introduction

Long-time integration is an effective and important method for detecting dim targets in noise [1]. However, for targets with high relative radial velocity and acceleration, there will be severe range migration in the received echoes. For a constant velocity target, the trace of the received echo is a straight line, and for a constant accelerating target, the trace of the received echo is a parabola, it's quite difficult to perform long-time integration.

Carlson proposed a method based on Hough transform to realize long-time integration for detecting dim targets [2]. The standard Hough transform method performs well in the situation of constant velocity targets, but degrades dramatically in the situation of manoeuvring targets. Besides it’s computationally inefficient. Since the randomized Hough transform can efficiently detect line and curve, we present a

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randomized Hough transform based approach to detect dim manoeuvring targets. The performance of the proposed method is evaluated under several scenarios.

2. Hough Transform

The Hough transform is a feature detection method originally developed for the detection of straight lines in an image space corrupted by noise [3, 4]. A line can be defined by the angle $\theta$ of its perpendicular to the origin and the distance $\rho$ from the origin to the line along the perpendicular. The Hough transform then maps points in the Cartesian data space onto curves in Hough parameter space defined by

$$\rho = x \cos \theta + y \sin \theta, \quad \theta \in (-\pi, \pi]$$

(1)

The mapping requires stepping through $\theta$ from $-\pi$ to $\pi$, and calculating the corresponding $\rho$ for every point in Cartesian coordinate. It’s computationally expensive [5, 6].

3. Randomized Hough transform for detecting targets

Randomized Hough transform randomly samples points in the Cartesian data space, and then maps them into Hough space [5]. Randomized Hough transform reduces the number of the points in the Cartesian data space which should be mapped to Hough space.

3.1. Constant velocity target detection

For a constant velocity target, the trace of the received echo in pulse-range domain is a straight line which isn’t perpendicular to range axis. When using randomized Hough transform to detect targets, we first divide the pulse-range domain into cells of dimension $\Delta r$ by $\Delta p$, then define a data matrix $D$ for these measurements with signal power exceeding a predetermined primary detection threshold

$$D = \begin{bmatrix} r_1 & r_2 & \cdots & r_M \\ p_1 & p_2 & \cdots & p_M \end{bmatrix}$$

(2)

where each columns represents the pulse and range coordinates of the primary threshold crossings, and $M$ is the total number of threshold crossings. A sample data matrix $D'$ from data matrix $D$ can be defined as

$$D' = \begin{bmatrix} r'_1 & r'_2 & \cdots & r'_N \\ p'_1 & p'_2 & \cdots & p'_N \end{bmatrix}$$

(3)

where $N$ is the total number of samples. A transformation matrix $H$ is defined as

$$H = \begin{bmatrix} \cos \theta_1 & \sin \theta_1 \\ \cos \theta_2 & \sin \theta_2 \\ \vdots & \vdots \\ \cos \theta_K & \sin \theta_K \end{bmatrix}$$

(4)
where \( \{ \theta \}^K_{i=1} \) are \( K \) discrete values from 0° to 180° for the cells of Hough space. The matrix \( \mathbf{H} \) is pre-computed and its size depends only on the Hough space quantization. This mapping from pulse-range domain into Hough space is implemented by matrix multiplication which produces a \( K \times N \) matrix \( \mathbf{R} \)

\[
\mathbf{R} = \mathbf{H} \cdot \mathbf{D}' = \begin{bmatrix}
\rho_{1,\theta_1} & \cdots & \rho_{N,\theta_1} \\
\vdots & \ddots & \vdots \\
\rho_{1,\theta_K} & \cdots & \rho_{N,\theta_K}
\end{bmatrix}
\tag{5}
\]

Each column of \( \mathbf{R} \) contains the values of \( \rho \) for one of the Hough space sinusoids. Hough space is quantized in \( \rho \) and \( \theta \) dimensions with each cell of size \( \Delta \rho \times \Delta \theta \). When the primary threshold crossings from a constant velocity targets are mapped into the Hough space, their powers are integrated in the corresponding Hough parameter cell. The target velocity can be estimated from the peak location in Hough space through

\[
\hat{v} = \frac{\hat{l}}{(l - 1) \text{PRI} \cdot \tan(-\hat{\theta})}
\tag{6}
\]

where \( \hat{l} \) and \( \hat{\theta} \) are the value of quantized cell which the peak is located in, and \( \text{PRI} \) is pulse repetition interval.

### 3.2. Constant acceleration target detection

The randomized Hough transform is an effective technique for detecting targets travelling in straight line. It can also be applied to detect constant accelerating targets whose trace is a parabola. A parabola can be represented by

\[
r = s_0 + vt + \frac{1}{2}at^2
\tag{7}
\]

where \( s_0, v, a \) are the parameters of parabola, \( t = (p - 1) \cdot \text{PRI} \), \( p \) is the number of the pulse, \( \text{PRI} \) is pulse repetition interval.

We define a data matrix \( \mathbf{D} \) representing the primary threshold crossings in pulse-range domain

\[
\mathbf{D} = \begin{bmatrix}
r_1 & r_2 & \cdots & r_M \\
p_1 & p_2 & \cdots & p_M
\end{bmatrix}
\tag{8}
\]

where each columns represents the pulse and range coordinates of the primary threshold crossings, and \( M \) is the total number of threshold crossings. We randomly select \( N \) groups from \( \mathbf{D} \), each group includes 3 columns. Let the crossings of the \( i \)th group be \( (r_j, p_j), (r_k, p_k), (r_m, p_m), i = 1, 2, \ldots, N \), equation (7) can be solved from every group of three measurements. Let the solver of equation (7) based on \( i \)th group be \( (s_{0i}, v_i, a_i) \). The velocity and acceleration estimates can be described as
\[
\hat{v} = \frac{\sum_{i=1}^{N} v_i}{N} \quad \hat{a} = \frac{\sum_{i=1}^{N} a_i}{N}
\]  

respectively.

4. Simulation Examples

In this section, three scenarios are implemented for the purpose of evaluating the performance of the proposed method. The parameters in the simulation are listed in Table 1.

Table 1. Parameter of radar

| Parameter of radar                                |     |
|--------------------------------------------------|-----|
| Carrier frequency \( f_c (GHz) \)               | 0.2 |
| Bandwidth \( B (MHz) \)                         | 100 |
| Uncompressed pulse width \( \tau_u (\mu s) \)    | 5   |
| PRF \( (Hz) \)                                  | 1000|
| Number of consecutive pulses                     | 256 |

4.1. Example 1

In the first scenario, we consider a target with 200m/s radial velocity in a noise free environment. Fig. 1(a) shows the echoes of 256 pulses after pulse compression in pulse-range domain. Fig. 1(b) gives the accumulated power after randomized Hough transform. Fig. 1(c) is the mesh plot of the accumulated power in Hough space. Targets are declared when the accumulated power in the Hough parameter space crosses the secondary threshold.

Fig. 1 Simulation results of the first scenario  (a) Echoes in pulse-range domain (b) Accumulated power after randomized Hough transform. (c) Mesh plot of the accumulated power in Hough space

4.2. Example 2

In the second scenario, we consider a target with 200m/s radial velocity in a noise environment. The SNR is -18.41dB. Fig. 2(a) shows the echoes of 256 pulses after pulse compression in pulse-range domain. Fig. 2(b) shows the trace of the target in pulse-range domain. Fig. 2(c) and Fig. 2(d) give the plot and mesh plot of the accumulated power after randomized Hough transform, respectively.

Fig. 2 Simulation results of the second scenario (a) Echoes in pulse-range domain (b) Trace of the target in pulse-range domain (c) and (d) Mesh plot of the accumulated power after randomized Hough transform.
Fig. 2 Simulation results of the second scenario (a) Echoes in pulse-range domain (SNR=-18.41dB) (b) Trace of the target in pulse-range domain (c) Accumulated power after randomized Hough transform. (c) Mesh plot of the accumulated power in Hough space

4.3. Example 3

In the third scenario, we consider a target with 200m/s initial radial velocity and 20m/s² radial acceleration in a noise environment. The SNR is -7.62dB. Fig. 2(a) shows the echoes of 256 pulses after pulse compression in pulse-range domain. Fig. 2(b) shows the trace of the target in pulse-range domain. It’s a parabola. Fig. 3(c) and Fig. 3(d) gives the velocity and acceleration estimates of the targets under different Monte Carlo (MC) runs. The relative root mean square error (RMSE) in velocity is 4.3%, and the relative RMSE in acceleration is 6.78%.
Fig. 3 Simulation results of the third scenario (a) Echoes in pulse-range domain (SNR=-7.62dB) (b) Trace of the target in pulse-range domain (c) Velocity estimate under different MC runs (d) Acceleration estimate under different MC runs

5. Conclusions

This paper presents a method based on randomized Hough transform to detect dim maneuvering targets in noise. Both constant velocity target and constant accelerating target are considered. The effectiveness of this proposed method is evaluated under several scenarios.

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