Multi-target Particle filter addressing Ambiguous Radar data in TBD

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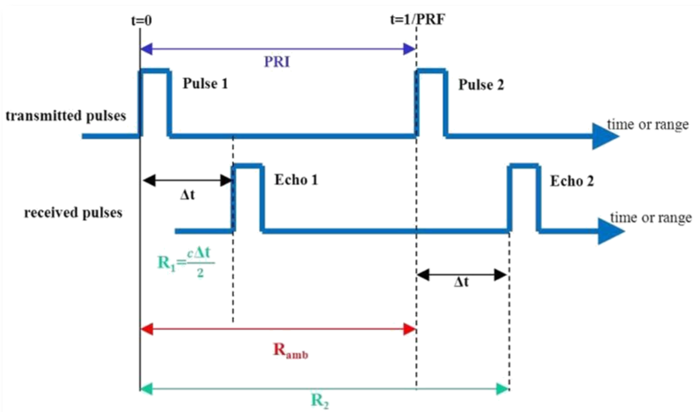
Abstract

The problem of Multi-target tracking, based on raw Radar data ambiguous in Range and Doppler, is addressed. A modeling setup, including Range/Doppler ambiguities and eclipsing effects, is introduced for a Track-Before-Detect (TBD) surveillance application. This leads to a fairly straightforward Particle Filter (PF) implementation. The designed PF succeeds in resolving Detection, Tracking, Ambiguity and Eclipsing problems over time. An interesting extension would be to also include clutter effects both in Doppler and Range.

Ambiguities



Range ambiguity

A second pulse is transmitted prior to the return of the first pulse. This causes reflected signals to be folded, so that the apparent range is a modulo function of the true range.

Target apparent range

$$r_{app} \equiv r_{true} \pmod{\frac{c}{2\ \mathrm{PRF}}}$$

Doppler ambiguity

Phase variation from pulse to pulse instead of frequency shift. This causes reflected signals to be folded, so that the apparent radial velocity is a modulo function of the true radial velocity.

Target apparent radial velocity

$$v_{app} \equiv v_{true} \pmod{\frac{\mathrm{PRF}\ \lambda}{2}}$$

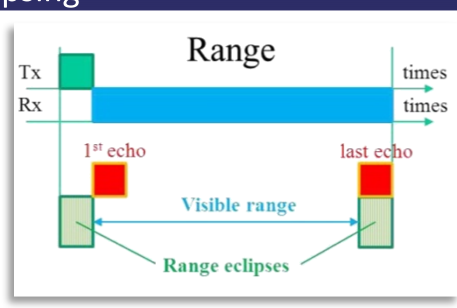
Eclipsing

Range eclipsing

Pulse eclipsing occurs due to the receiver being switched off while the radar is transmitting another pulse.

Blind range

$$r_{ecl} = \tau_{pulse} \cdot c.$$

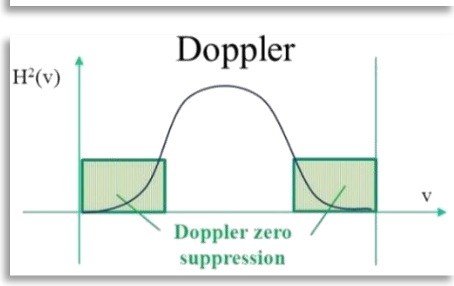


Doppler eclipsing

A blind velocity occurs when the Doppler frequency falls close to the PRF.

Blind velocity

$$d_{ecl} = n \frac{\lambda\ \mathrm{PRF}}{2},\ n \in \mathbb{N}^*$$



This folds the return signal into the same filter as stationary clutter reflections.

Modeling

State vectors $\mathbf{x}_{k,m} = [\mathbf{s}_{k,m}, \rho_{k,m}, m_{k,m}]^T \quad (m \in \{1, M\})$

- $\mathbf{s}_{k,m} = [x_k, \dot{x}_k, y_k, \dot{y}_k]$ m^{th} target position and velocity;
- $\rho_{k,m}$ modulus of the m^{th} target amplitude;
- $m_{k,m}$ binary Markov variable modeling the m^{th} target existence.

Dynamic model

	$m_{k-1,m} = 0$	$m_{k-1,m} = 1$
$m_{k,m} = 0$	Target state is not defined	
$m_{k,m} = 1$	1) $(x_{k,m}, y_{k,m}) \sim \mathcal{U}_{Obs_{Radar}}$ 2) $(\dot{x}_{k,m}, \dot{y}_{k,m}) \sim \mathcal{U}_{\mathcal{V}}$ $\mathcal{V} = \{(\dot{x}, \dot{y}) \mid v_{min} \leq \sqrt{\dot{x}^2 + \dot{y}^2} \leq v_{max}\}$ 3) $\rho_{k,m} \sim \mathcal{U}([\rho_{min}, \rho_{max}])$	$\mathbf{x}_{k,m} = F\mathbf{x}_{k-1,m} + \mathbf{v}_{k-1,m}$

Measurement model

$$\underbrace{\mathbf{z}^{ijl}_{\rho,k}}_{\text{Received signal}} = \sum_{m=1}^{M} m_{k,m} \underbrace{\rho_{k,m}\ e^{i\varphi_k}}_{\text{Complex amplitude}} \underbrace{h^{ijl}(\mathbf{s}_{k,m})}_{\text{Value of the reflection form of the } m^{th} \text{ target in the cell (ijl)}} + \underbrace{\mathbf{w}^{ijl}_k}_{\text{Complex white Gaussian noise i.i.d.}}, \quad \varphi_k \in (0, 2\pi)$$

Let us define the reflection form $h^{ijl}(s_{k,m})$ as

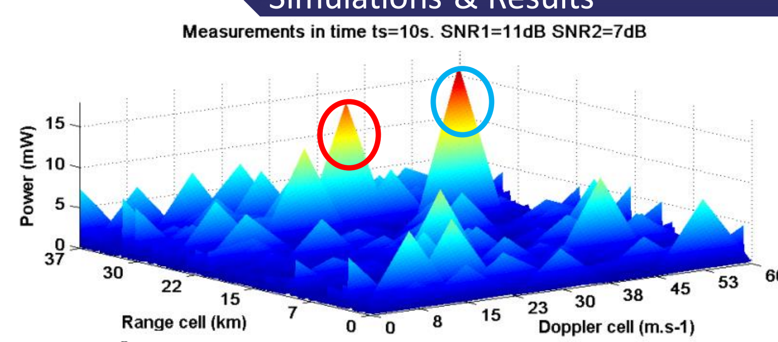
$$h^{ijl}(\mathbf{s}_{k,m}) := e^{-\frac{(r_i - r_k^m)^2}{2R} - \frac{(d_j - d_k^m)^2}{2D} - \frac{(b_l - b_k^m)^2}{2B}},$$

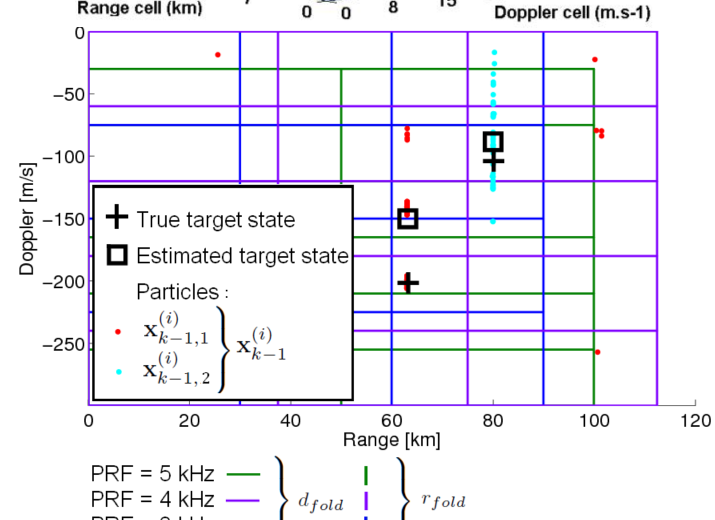
$$i = 1, \ldots, N_r,\ j = 1, \ldots, N_d,\ l = 1, \ldots, N_b \text{ and } k \in \mathbb{N}$$

with,

- Apparent target range: $r = \sqrt{x^2 + y^2} \left(\mathrm{mod} \frac{c}{2\ \mathrm{PRF}}\right)$
- Target azimuth: $b = \arctan\left(\frac{y}{x}\right)$
- Apparent target doppler: $d = \frac{(x\ v_x + y\ v_y)}{\sqrt{x^2 + y^2}} \left(\mathrm{mod} \frac{\mathrm{PRF}\ \lambda}{2}\right)$

Simulations & Results





The designed PF, initially with a large estimation error due to ambiguous data, identifies the targets range and radial velocity, and then converges to the targets state.

The proposed method can adapt to any type of waveform and allows you to fully benefit from the frequency agility of the radar.

Aknowledgement

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The research has been carried out in the MC IMPULSE project:
https://mcimpulse.isy.liu.se.

References

[1] M.I. Skolnik. *Introduction to radar systems*. McGraw-Hill, Inc., Singapore, 2nd ed., 1981.

[2] Y. Boers and H. Driessen. Multitarget Particle Filter Track-Before-Detect application. *IEE Proceedings on Radar, Sonar and Navigation*, vol.151, p.351–357, 2004.

[3] F. Katsilieris and Y. Boers and H. Driessen. Sensor management for PRF selection in the Track-Before-Detect context. *Proceedings of the IEEE Radar Conference*, 2012.