Passive Radar Tutorial Review

Passive Radar Definition

Passive radars are a class of radars that detect and track targets by processing EM waves reflections emitted by existing sources used for other purposes. Those sources are called illuminators of opportunity. Good IO must have high enough frequency and large bandwidth, such that the resolution is good enough for PR capabilities. Passive radars are bistatic radars, where the transmitting and receiving antennas are not collocated.

Passive Radars Bistatic Geometry

The bistatic radar geometry is an ellipse, shown in figure 1. The transmitter and the receiver are located at the foci and are separated by a distance L, the baseline.

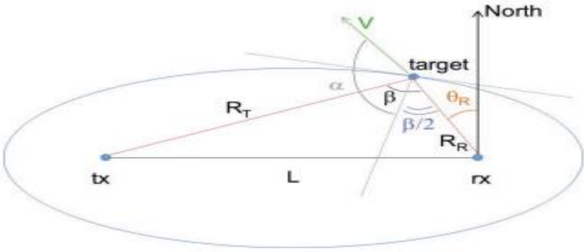

Figure 1. Bistatic radar geometry

Bistatic Range

The bistatic range is calculated from the time difference of arrival (TDoA), which is the time delay between the direct signal and its produced echoes. The bistatic range is calculated as given below, Eq.1.

$$R_{bis} = c \times (T_2 - T_1) = c \times \left(\frac{R_R+R_T}{c} - \frac{L}{c}\right) = R_R + R_T - L \quad (1)$$

Bistatic Doppler

Doppler frequency shift is the shift in frequency due to the motion of the target, as the transmitter and receiver are stationary in the case of a PR. The bistatic frequency (f_{bist}) is the rate of change of the bistatic range with respect to time, which simplifies as given below, Eq. 2. Note that β is the angle between the transmitter and the receiver and α is the angle between the velocity vector and the line bisecting β. The doppler frequency shift is *positive* for approaching targets ($0° \leq \alpha \leq 90°$), and *negative* for receding targets ($90° \leq \alpha \leq 180°$).

$$f_{bist} = \frac{\partial}{\partial t} R_{bist}(t) = \frac{\partial}{\partial t}[R_R(t) + R_L(t)] = \frac{v}{\lambda} \cos(\alpha) \cos\left(\frac{\beta}{2}\right) \quad (2)$$

Bistatic Resolution

The bistatic resolution equation is given by Eq. 3, note that unlike with monostatic radars, δR_{bist} is a function of the target's position.

$$\delta R_{bist} \approx \frac{c}{2B\cos\left(\frac{\beta}{2}\right)} \quad (3)$$

Radar Equation

The radar equation, given by Eq. 4, relates the power transmitted from the illuminating source to the power received by the receiver. The radar equation also allows determining the maximum detectable range, and the expected SNR of a given case.

$$P_r = \frac{P_T\, G_T\, \lambda^2 G_R\, \sigma}{(4\pi)^3 R_T^2 R_R^2} \quad (4)$$

Processing Scheme

In contrast to active radars, the transmitted signal (illuminating signal) is not a priori; thus, the direct signal must be measured. A channel called the "reference receiver" collects it from an antenna directed at the transmitter of the illuminator of opportunity. The signal's reflections are collected by the "surveillance receiver."

The direct signal is the strongest signal received at the surveillance channel; it travels a shorter distance (L, baseline) and is also not attenuated due to reflection off the target. For that, the processing scheme begins with the suppressing of the direct signal ***(disturbance cancellation)*** by spatially directing the minimum gain loop of the receiving antenna towards the source transmitter.

Due to the low quality of the doppler of the received signals, the two signals are correlated ***(range – doppler cross – correlation)***. The replicas of the direct signal (s_{ref}), time delayed (τ – potential TDoA), and doppler modulated (f_d – potential doppler frequency shift) are correlated with the surveillance channel signal (s_{urv}). This is described by the ambiguity function given by Eq. 5. The resulting 2-dimentional range- doppler matrix allows us to estimate the bistatic range and frequency of a given target.

$$X(\tau, f_D) = \int_{-\infty}^{\infty} s_{surv}(\tau) s_{ref}^{*}(t-\tau) e^{-2\pi f_D \tau} d\tau \qquad (5)$$

Target Detection

Target detection is determining whether the power level of the signal's echoes received correctly recognizes the presence of a target at a particular range-doppler cell. A target is said to be detectable if the total energy from the target exceeds *the threshold detection level (T). The level is* set by taking into consideration the two probabilities, the detection probability and the false alarm probability, or the *statistical characteristics of the disturbances.*

Target Tracking

One way of tracking the target in the cartesian domain is by using the DoA (direction of arrival) and range measurements method, where the target is localized by intersecting the cone of the direction of arrival (DoA), which is determined by the receiver's antenna beamforming, with the constant range ellipsoid determined from (TDoA).

Another way is using the ellipsoid intersection method. From the TDoA, a constant range ellipsoid profile is produced for each transmitter-receiver pair, and the target is at the intersection of the ellipsoids.

Figure 2 depicts a multi-static radar system of three transmitters (black circles) and a receiver (red circle). The figure assumes the simple case of zero elevation (ellipsoids reduce to ellipses). The target is at the intersection of all the ellipses, and all other intersections are ghosts.

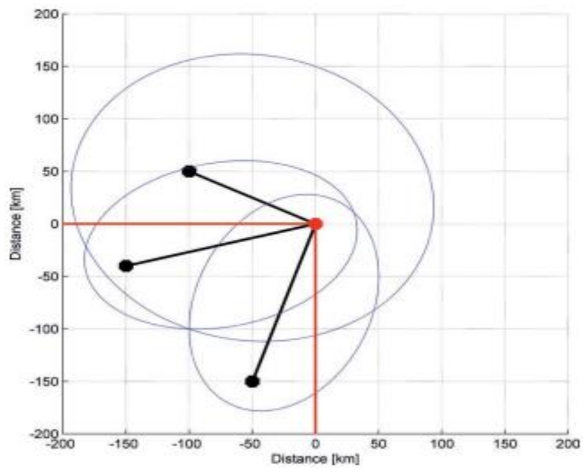

Figure 2. constant range profiles of three transmitter – reciver pairs.