Evaluation of Netted Radar Performance

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Abstract

In this paper, the performance of netted radar is evaluated in terms of the netted version of sensitivity and netted version of ambiguity function. A set of software tools have been developed to assess netted radar sensitivity and ambiguity properties in both tow dimensional and three dimensional spaces. Simulation results revealed that netted radar sensitivity is not only dependent on radar parameters, but also on system geometry. It is also shown that the degradation of range and Doppler resolution shown in the two dimensional netted radar cases is reduced in the three dimensional netted radar cases when appropriate system geometry is selected.

Keywords: Netted radar, bistatic radar, sensitivity, ambiguity function

Introduction

Netted radar employs several spatially separated transmitters and receivers. This topology offers some inherent advantages over the traditional monostatic or bistatic radar, where a single transmitter and receiver are collocated for the former, and are often spatially separated by a distance comparable to the target distance for the later [1] [2].

An advantage of netted radar is the ability to optimize the coverage area. Owing to the use of multiple transmitting and receiving stations, the geometry of the netted radar can be tailored to meet the needs of specific requirements. Combined with suitable data fusion algorithms, extension of the coverage area in a given direction is achievable. Another advantage is the increase of system sensitivity. Due to the additional use of radar transmitters, the received signal power will be augmented, leading to an increase in overall signal to noise ratio (SNR), and consequently system sensitivity. In netted radar cases, the target is observed from multiple perspectives rather than from a single direction. This makes better use of the scattered energy. Target classification and recognition can be improved due to the more information retrieved from different perspectives. Also, the survivability and reliability are improved significantly in netted radar systems. The loss of one or even several stations may not be completely fatal and leads to the concept of graceful degradation, because there are still some other stations working properly. Additionally, the passive operation of receiving stations makes netted radar less vulnerable to physical attacks.

Recent development in relevant technologies such as multi-channel antennas with electronic beam steering, high speed digital processors and computers, transmission lines with high capacity, and precise synchronization systems, give rise to the possible implementation of low cost, coherent, and stable netted radar systems.

Sensitivity

Radar sensitivity is perhaps the most important parameter used to evaluate the performance of radar systems. It indicates the radar's ability to detect the presence of a target. It is expressed as the received signal to noise ratio (SNR), which is calculated by radar range equation. Normally the minimum acceptable signal to noise ratio can be calculated when both the required probability of detection and the probability of false alarm are given. Radar sensitivity is affected by many parameters, including radar factors, such as transmitted power, antenna gain, transmitted wavelength, etc, which can be managed by radar designers, and other factors, such as target cross section, target distance from radar receivers, etc, which cannot be chosen.

Monostatic sensitivity can be calculated according to the conventionally used monostatic radar equation [3]. Monostatic and sensitivity plots are shown in figure 1 in both two dimensional and three dimensional spaces. In this simulation, the transmitted power is 6 kw and the detection threshold is set as 13db. It is assumed that the target cross section does not change with look angles. It is shown that monostatic radar gives a spherical coverage area in three dimensional space, whereas a circular area in two dimensions. This is resulted from the isotropic transmission of radiated energy.

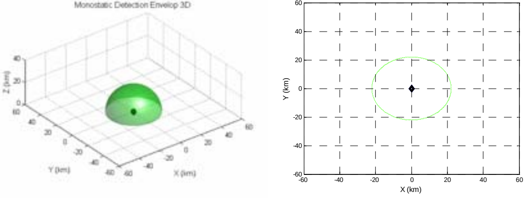

Figure 1 *3D & 2D Monostatic radar sensitivity*

The netted version of radar equation is developed based on the bistatic radar equation. Fully coherent radar networks are considered, which means the radars comprising the network have a common and highly precise knowledge of time and space. The whole network is composed of m transmitters and n receivers. It is assumed that the radar network is well synchronized such that each receiver is able to receive and process echoes scattered from target due to any transmitter in the network. The total netted radar sensitivity is calculated by summing up returns from every bistatic pairs, which is given by:

$$SNR_{netted} = \sum_{i=1}^{m} \sum_{j=1}^{n} \frac{P_{ti} G_{ti} G_{rj} \sigma_{ij} \lambda_i^2}{(4\pi)^3 k T_s B_i R_{ti}^2 R_{rj}^2 L_{ij}} \quad (1)$$

where

P_{ti} = i th transmitted power

G_{ti} = i th transmitter gain

G_{rj} = j th receiver gain

σ_{ij} = radar cross section (RCS) of the target for i th transmitter j th receiver

λ_i = i th transmitted wavelength

T_s = receiving system noise temperature

B_i = bandwidth of the matched filter for the i th transmitted waveform

L_{ij} = system loss for i th transmitter, j th receiver

R_{ti} = distance from i th transmitter to target

R_{rj} = distance from target to j th receiver

Three dimensional and two dimensional netted radar sensitivity examples are shown in figure 2, figure 3 and figure 4 respectively, with varying system geometry. The netted radar is composed of three transmitters and three receivers. The transmitted power from each transmitter is 2 kw, giving the same total transmitted power as the previous monostatic example. In other words, the total power in all the systems is kept constant for comparison.

In figure 2, the three transmitters and receivers are collocated. This results in a spherical coverage area which is similar to the monostatic case due to the symmetry of system configuration, but the radius is greater than the monostatic case. This is because each receiver accepts echoes from every transmitter, giving an increase of the totally received power and therefore enlarged coverage area. This means that netted radar makes better use of transmitted energy than monostatic radar.

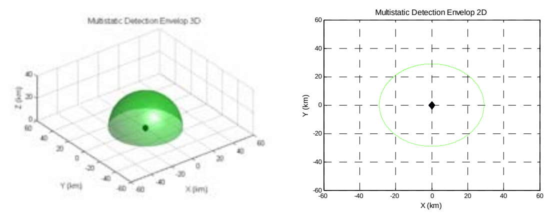

Figure 2 *3D & 2D Netted radar sensitivity-collocated transmitters and receivers*

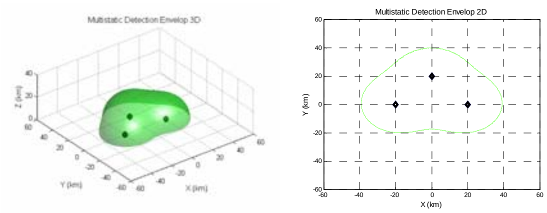

Figure 3 *3D & 2D Netted radar sensitivity-dispersed transmitters and receivers*

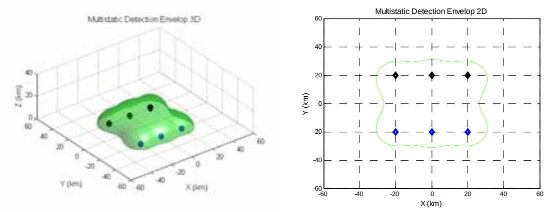

Figure 4 *3D & 2D Netted radar sensitivity-fully dispersed transmitters and receivers*

In figure 3, the three transmitter-receiver pairs are dispersed. It is shown that the coverage area in the first two dimensions is enlarged, whereas it is reduced in the third dimension of height. This is expected as the total transmitted energy is the same as for figure 2. In figure 4, the transmitters and receivers are fully dispersed. In this case, the coverage area in the first two dimensions is increased further, while it is reduced further in the third dimension of height.

These figures also illustrate that the radar design now has an additional degree of freedom that allows coverage to be tailored to a particular application.

The ambiguity function

It is widely recognised that the ambiguity function is an important tool to evaluate radar performance in terms of target resolution and clutter rejection. The concept of ambiguity function was firstly defined by *Woodward* [4]. It can be seen as the absolute value of the envelope of the output of a matched filter when the input to the filter is a Doppler shifted version of the original transmitted signal, to which the filter is matched [5]. If *u (t)* is the complex envelop of the transmitted signal, the ambiguity function is calculated by:

$$|\chi(\tau, f)| = \left| \int_{-\infty}^{+\infty} u(t)u^*(t-\tau)e^{j2\pi ft}dt \right| \qquad (2)$$

Monostatic radar ambiguity is fairly well developed, and a variety of examples can be found in literature. Bistatic radar ambiguity is developed by *Tsao et. al.*[6]. It should be noted that the ambiguity function is typically plotted with respect to the delay-Doppler plane. However, it is more meaningful to plot ambiguity function on a range-velocity plane, because there two are the primary parameters of interest, and extremely useful to show the influence of system geometry on the shape of ambiguity diagrams.

Here the netted radar ambiguity function is formulated based on the bistiatic radar ambiguity calculation. It is assumed that the radar network is composed of N transmitters and one single receiver, such that it is easy to choose the receiver as the common reference point. In this case the radar network comprised N bistatic pairs. The analysis is based on the matched filter processing at the receiver. There are some important assumptions for the formulation of netted radar ambiguity function. Firstly, the target is slowly fluctuating and its scattering properties do not change with the look angles. Secondly, the transmitted signals are the same and the filter is matched to the original transmitted signal. A very important assumption is that the network is coherent. This implies that the echoes arriving at different time instances can be processed jointly. Similar to the bistatic radar ambiguity analysis, the netted radar ambiguity is developed by the following three steps:

1. To calculate bistatic ambiguity function for each transmitter-receiver pair by equation (2).

2. To calculate weighting factor according to received signal intensity.

$$P_{ri} = \frac{P_{ti} G_{ti} G_r \lambda^2 \sigma}{(4\pi)^3 (R_{ti} R_r)^2}, i = 1,2...N \quad (3)$$

$$w_i = \frac{P_{ri}}{Max(P_{ri})} \quad (4)$$

3. To formulate netted radar ambiguity function using the results form previous calculations:

$$\chi_{netted} = \left| \sum_{i=1}^{N} w_i \chi_i \right|^2 \quad (5)$$

A three dimensional netted radar model is developed for a comprehensive understanding of netted radar ambiguity performance. It is assumed that the fixed transmitters and receiver are located in one plane and the target is moving in another plane which is parallel to the transmitter-receiver plane. The three dimensional netted radar topology used for the netted radar ambiguity analysis in the rest of this paper is shown in figure 5.

A vectorial approach is used to calculate the two important parameters, delay and Doppler, which are used for ambiguity function calculation.

$$\tau = \frac{\left|\overrightarrow{R_t}\right| + \left|\overrightarrow{R_r}\right|}{c} \quad (6)$$

$$\begin{aligned} f_b &= \frac{1}{\lambda}[\frac{d}{dt}(\overrightarrow{R_t} + \overrightarrow{R_r})] \\ &= \frac{1}{\lambda}[\frac{\overrightarrow{R_t} \cdot \overrightarrow{V}}{\left|\overrightarrow{R_t}\right|} + \frac{\overrightarrow{R_r} \cdot \overrightarrow{V}}{\left|\overrightarrow{R_r}\right|}] \end{aligned} \quad (7)$$

where $\vec{V}$ is the target velocity vector, and $\vec{R}_t$ and $\vec{R}_r$ are target to transmitter range vector and target to receiver range vector, respectively.

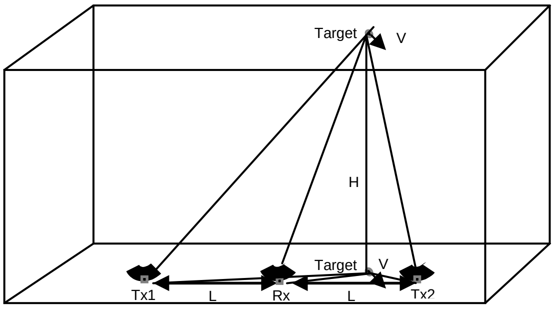

Figure 5 *3D Netted radar system geometry*

The signal used for netted radar ambiguity function simulation is a coherent pulse train consisting of three rectangular pulses with 40 µs pulse length, 100 µs period, and carrier frequency ω_c $=3\times10^8$ rad/s. Only target close to baseline cases are simulated here, because this is where the deterioration of ambiguity properties appears in bistatic cases.

In the first group of simulation, the baseline is 10 km long; the target is 6 km away from the receiver for the two dimensional geometry with 600 m/s velocity. Figure 6 shows the two dimensional ambiguity diagrams, while figure 7 and figure 8 shows three dimensional ambiguity diagrams with a target height of 20 km and 4 km, respectively. Three dimensional examples with different target heights are presented to observe the effect of varying target height on the form of netted radar ambiguity properties.

Figure 5 illustrates that in the two dimensional netted radar cases, when the target is close to a bistatic baseline, the system resolution in both range and velocity domains deteriorates dramatically. In this case, the netted radar system is not capable of resolving target parameters. In figure 7, the target is far from the transmitter-receiver plane. Both range and velocity resolutions are improved greatly. However, if the target is not far enough from the transmitter-receiver plane, the improvement is not satisfactory. This is shown in figure 8. In other words, in three dimensional netted radar cases, the target should be far enough from the transmitter-receiver plane to achieve satisfactory improvement in range and velocity resolution.

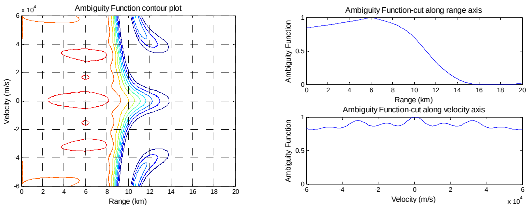

Figure 6 *2D Netted radar ambiguity function*

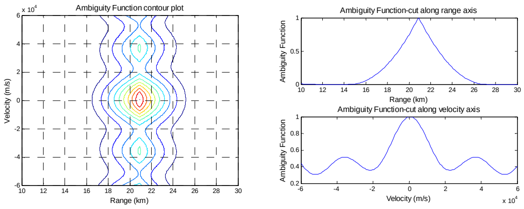

Figure 7 *3D Netted radar ambiguity function-H=20km*

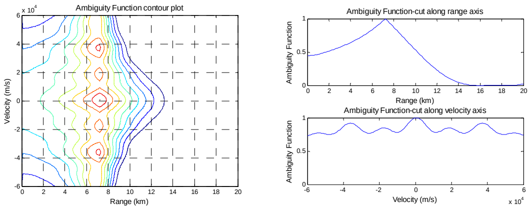

Figure 8 *3D Netted radar ambiguity function-H=4km*

The following examples show the ambiguity function diagrams of the netted radar with a long baseline, where the baseline length is 100 km, which is 10 times greater than the former examples. In this case, the target is 60 km away from the receiver for the two dimensional case.

Figure 9 shows the degradation in range and velocity for the two dimensional netted radar case. Figure 10 shows the three dimensional ambiguity diagrams with a target height of 20 km. It is observed that, although the absolute value of target height is big enough, satisfactory improvement of range and velocity resolution is still not achievable. This is because the relative value of target height is still not big enough; i. e. the target height to baseline length ratio is not big enough.

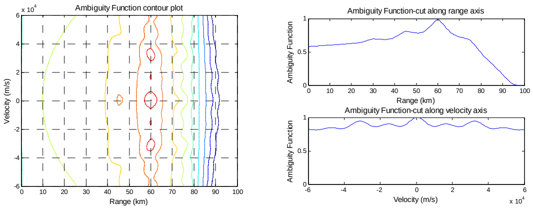

Figure 9 *2D Netted radar ambiguity function-long baseline*

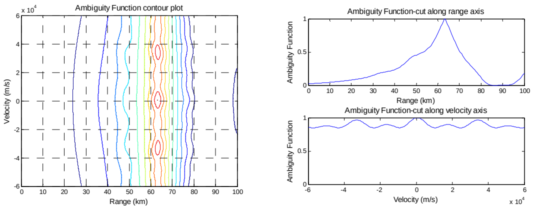

Figure 10 *3D Netted radar ambiguity function-long baseline*

Conclusions and future work

Two important aspects of netted radar performance have been investigated in this paper. They are sensitivity and ambiguity. Mathematical model and simulation results have been shown in both two dimensional and three dimensional spaces.

It has been shown that netted radar sensitivity is not only dependent on radar parameters, but also on system geometry. Netted radar offers more flexible arrangement of system geometry than traditional monostatic systems, leading to the possibility of configuring radar nodes to form a satisfactory coverage area. It has also been demonstrated that the degradation of range and Doppler resolution shown in the two dimensional netted radar cases can be reduced in three dimensional netted radar cases, when appropriated system configuration is selected. The target height to baseline ratio plays an important role in three dimensional netted radar ambiguity performance and short baselines perform better than long baselines. As a result, it is possible to change netted radar parameters to achieve satisfactory range and Doppler resolution.

The next step of this work is to evaluate netted radar target localisation capabilities. This means how accurately netted radar can locate a target. Mathematical models and software simulation should be developed to examine netted radar target localisation in both far field and near field.

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