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Solution of inverse localization problem associated to multistatic radar system

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Abstract. This work deals with the problem of inverse localization by a target with the aim to retrieve the position of the target, given the intensity and phase of the electromagnetic waves scattered by this object. Assuming the surface cross section to be known as well as the intensity and phase of the scattered waves, the target position was reconstructed through the echo signals scattered of each bistatic. We develop in the same time a multistatic ambiguity function trough bistatic ambiguity function to investigate several fundamental aspects that determine multistatic radar performance. We used a multistatic radar constructed of two bistatic radars, two transmitters and one receiver.

1 Introduction

Research in radar engineering over the last few decades has been mainly focused on improving target detection, parameter estimation accuracy, and reliable target classification in monostatic radar and bistatic radar. Generally, the transmitter and receiver share a common antenna, which is called a monostatic radar system. While a bistatic radar consists of separately located transmitting and receiving sites [1]. Despite recent advancement in radar component technology such as antennas, transmitters, receivers and processors, modern high requirements cannot always be met by traditional radars in many cases which gave birth to multistatic radar system [2].

Multistatic radar systems differ from traditional monostatic systems, or bistatic systems characterized by a separated transmitter and receiver; they consist of multiple transmitters and/or receivers.

A multistatic system consisting of multiple transmitters and one or more receivers can transmit multiple waveforms from collocated or distributed antennas [3], possibly illuminating a larger area than a monostatic system. The power of the transmitting antenna is a limiting factor on the extent of radar's visibility [4]; the use of multiple transmitting antennas to illuminate an area may help overcome the physical limitations of amplifier power and antenna aperture sizes [5].

Multistatic radar has been an area of intense research in recent years due to the inherent flexibility and importance of radar as an all-weather electromagnetic sensor and the additional theoretical advantages of a multistatic radar system. Traditional monostatic radars radiate electromagnetic energy from an antenna, the field propagates through space and is reflected in many directions from objects in the environment [6], and some of the reflected energy is received by the antenna of the radar, and through processing techniques information about the intercepted objects is extracted. Radar systems can be used to detect and track targets, detect moving targets in clutter rich environments, form images of stationary or moving targets or scenes, recognize meteorological conditions, and classify targets.

In this paper we aim to detect and localize two moving targets using multistatic radar with two bistatic radars, two transmitters and one receiver. We will simulate the first case with a polarimetric bistatic radar and secondly with a multistatic radar using two type of polarization, linear polarization and circular polarization.

2 Modeling and method

Radar can be classified by the topology of transmitting and receiving stations (i.e. by their locations). Both monostatic radar and bistatic radar employ a single transmitter and a single receiver. In the monostatic case, the transmitter and receiver are co-located and may share one common antenna, whereas in the bistatic case, the transmitter and receiver are spatially separated [7].

2.1 Bistatic Radar Model

Bistatic radar uses separate antennas at different locations for transmission and reception. Figure 1 shows a typical geometry of a bistatic radar, where a transmitter and a receiver are placed at two sites, separated by a distance L, normally comparable with the target distance, known as the baseline [8].

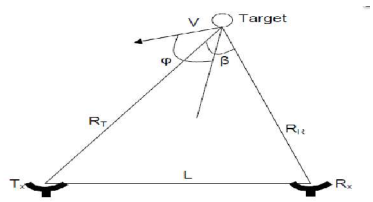

Fig.1 . bistatic radar topology

The angle between the transmitter and receiver with the vertex at the target is known as bistatic angle. In a bistatic radar system, the transmitter, receiver and target form the bistatic triangle, and furthermore the bistatic plane [5]. Unlike monostatic radar, bistatic radar usually measures the range sum, which equals to the total path length of the transmitter to target range R_t and the target to receiver range R_r.

$$R_t + R_r = \frac{1}{2}c\tau \qquad (1)$$

where τ is the total delay from transmission to reception, and c is the speed of radio wave propagation.

In a bistatic radar system, when the transmitter and receiver positions are fixed, the bistatic Doppler fb at the receiver site generated by the moving target is calculated by the time rate of change of the total path length of the transmitted signal, normalized by wavelength:

$$f_b = \frac{\frac{dR}{dt}}{\lambda} = \frac{\frac{d(R_t+R_r)}{dt}}{\lambda} \qquad (2)$$

where $\frac{dR}{dt}$ is the projection of target velocity onto the transmitter-to-target line-of-sight, given by:

$$\frac{dR_t}{dt} = V\cos(\phi - \beta/2) \qquad (3)$$

Then the total Doppler shift is given by:

$$f_b = \frac{2V\cos\phi\cos(\beta/2)}{\lambda} \qquad (4)$$

In the bistatic case, the transmitter and receiver are not collocated as in the monostatic case. The transmitter to target range and target to receiver range are R_t and R_r, respectively. The bistatic RCS depends on many factors such as look angle. It is not equal to monostatic RCS, and is often found to be close to the monostatic value measured along the bistatic bisector [2]. Similar to the derivation of the monostatic radar equation, the bistatic radar range equation is given by

$$R_tR_r = \left[\frac{P_tG_tG_r\sigma_b\lambda^2}{(4\pi)^3kT_sB(SNR)L}\right]^{\frac{1}{2}} \qquad (5)$$

Compared with monostatic radar range equation, a major difference here is that the range product replaces the range square.

2.2 Multistatic Radar

The idea of using several spatially separated, cooperative transmitting and receiving stations for effective energy use and better information retrieval has long been in the mind of radar engineers. However, there is no uniform terminology describing radar systems designed with this concept in mind. A couple of terms appear in the literature with slightly different definitions, such as multistatic radar [2] [9] [5], multisite radar [3], radar network [1], distributed radar [7] and netted radar [1]. Multistatic radar is used in this paper.
A typical arrangement of multistatic radar is showed in Figure 2. It is composed of three elements: radar stations, data processing units and the communication links between radar nodes. The basic components of netted radar are the traditional monostatic and bistatic radars.

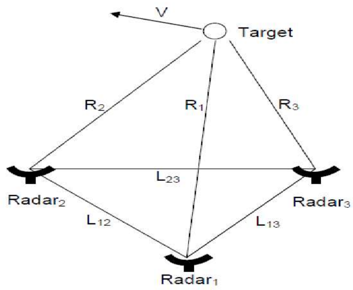

Fig.2 . Multistatic radar topology

Each station can be transmitting, receiving or both transmitting and receiving, giving rise to three operational modes: multiple monostatic operation, multiple bistatic operation and a combination of monostatic and bistatic operation. Most of the data received in radar stations are sent to the central unit for final processing.

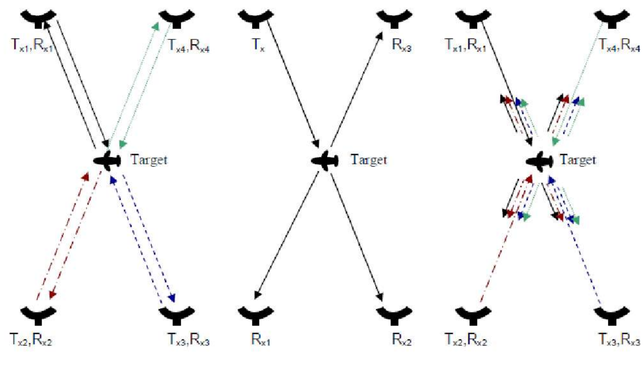

Fig.3 . Multistatic radar operation modes

As seen in figure 2 multistatic radar can be categorized as a multiple monostatic network, a multiple bistatic network, and a mixture of the two. In the multiple monostatic case, each radar can transmit a specific signal and receive the return originated from this unique transmitted signal only [1]. An example of the multiple bistatic case is a radar network comprising one common transmitter and N spatially separated receivers where each transmitter-receiver pair forms bistatic radar. Finally, when each station in the network can transmit and receive signals originated from any stations in the network, the system is fully netted.

2.2 Ambiguity function

The ambiguity function arose from detection and parameter estimation problems concerning a slowly fluctuating point target being observed in an additive white Gaussian noise [1]. It is widely recognized that the ambiguity function is an important tool to qualitatively assess radar performance in terms of resolution and clutter rejection. It should be noted that for a radar system the concept of resolution is different from accuracy. Resolution refers to the radar ability to distinguish different targets which are close to each other in terms of range and Doppler. It is obvious that the further separated in range and Doppler the two targets, the easier they will be distinguished one from the other. By passing through the received signal to a matched filter, the output is defined as ambiguity function, which is given by:

$$|\chi(\tau,\upsilon)| = \left|\int_{-\infty}^{\infty} u(t)u^*(t-\tau)\exp(j2\pi\upsilon t)\,dt\right| \quad (6)$$

The practical importance of the ambiguity function is that it describes the output signal from a matched filter when the input signal is time delayed by τ and Doppler shifted by v with respect to the nominal signal with which the matched signal is supposed to give the maximum output [4].

The two key parameters for ambiguity function calculation are the time delay τ , and the frequency shift v. From this definition it is seen that the ambiguity function associates two system parameters determining the radar performance, range and velocity, with two signal parameters, delay and Doppler. Therefore, it provides a tool to evaluate how well one can find the range and velocity of targets and how the design of signal can help.

As a useful tool, the ambiguity function is normally represented by graphical plots. Typically it is plotted in three dimensions with respect to the delay-Doppler plane. However, it is more meaningful to plot it on a range-velocity plane, because these two are the useful parameters for measurement, and extremely useful to show the influence of system geometry on the shape of ambiguity function.

3 Results and discussion

We used Matlab 2016 to simulate a multistatic radar system with two polarimetric bistatic radars to estimate the range and speed of two targets. The system operates at 300 MHz, using a linear FM waveform whose maximum the range resolution is 50 meters and the time-bandwidth product is 20.

Figure 4 shows the multistatic radar configuration with two polarimetric bistatic radars with two transmitters and one receiver, and the detected targets with the estimated positions.

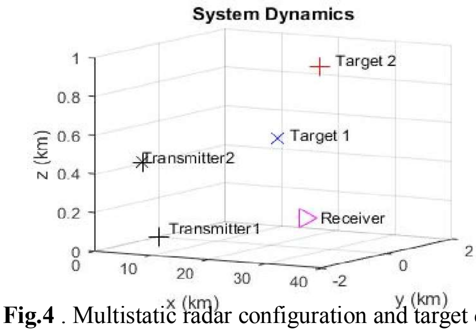

Fig.4 . Multistatic radar configuration and target detected positions

The Range-Doppler map simulation only shows the return from the first target. This is probably no surprise since both the transmit and receive array are vertically polarized and the second target maps the vertically polarized wave to horizontally polarized wave. The received signal from the second target is mostly orthogonal to the receive array's polarization, resulting in significant polarization loss.

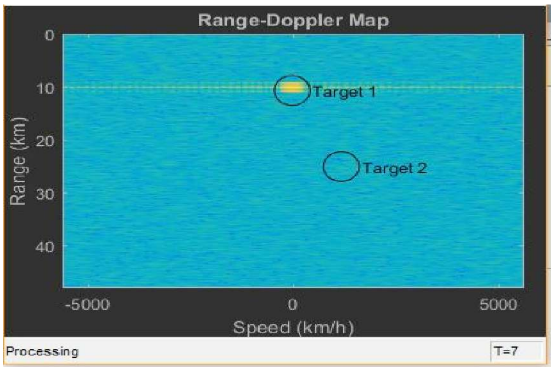

Fig.5. Multistatic radar range Doppler map with linear polarization

Vertical dipole is a very popular choice of transmit antenna in real applications because it is low cost and have an omnidirectional pattern. However, the previous simulation shows that if the same antenna is used in the receiver, there is a risk that the system will miss certain targets. Therefore, a linear polarized antenna is often not the best choice as the receive antenna in such a configuration because no matter how the linear polarization is aligned, there always exists an orthogonal polarization. In case the reflected signal bears a polarization state close to that direction, the polarization loss becomes huge.

One way to solve this issue is to use a circularly polarized antenna at the receive end. A circularly polarized antenna cannot fully match any linear polarization. But on the other hand, the polarization loss between a circular polarized antenna and a linearly polarized signal is 3 dB, regardless what direction the linear polarization is in. Therefore, although it never gives the maximum return, it never misses a target. A frequently used antenna with circular polarization is a crossed dipole antenna.

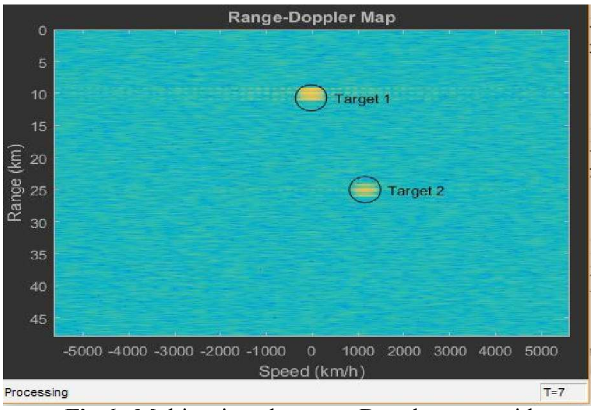

Fig.6 . Multistatic radar range Doppler map with circular polarization

The range-Doppler map now shows both targets at their correct locations.

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