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Multi-target Direction Measurement on Bistatic MIMO Radar

Jingfang Wang
School of Electrical & Information Engineering, Hunan International Economics University,
Changsha, China, postcode:410205
E-mail: matlab_bysj@126.com

Abstract

In recent years, multiple-input multiple output (MIMO) radar has been widespread concern in the domestic and foreign researchers. Bistatic radar draws on the great success of MIMO technology in the communications field and it has many advantages over conventional radar. In this paper, the direction angles estimations of bistatic MIMO radar are researched. To contrast traditional radar DOA estimates, the direction vector of the bistatic MIMO radar is the Knonecker plot of the emission vector and reception vector, that two-dimensional direction angles is estimated. To solve this problem, the principle of bistatic MIMO radar signal model is in-depthly researched.By proposing Capon dimensionality reduction method, the two-dimensional directions of the dual-based MIMO radar are estimated, and computer simulation is to verify the effectiveness of the method.

Keywords: *bistatic radar, multi-input multi-output (MIMO), direction-of-arrival (DOA), direction-of-departure (DOD), capon dimensionality reduction*

1. Introduction

Multiple input multiple output (MIMO) radar [1] which is proposed in recent years is a new system radar, It draws on a huge success in the field of communication technology of multiple input multiple output, has a lot of advantage, have shown potential for radar to make important contributions to the field. In recent decades, the overseas constantly introduced various high-altitude aircraft and missiles and a low-level high-speed cruise missiles (such as "tomahawk cruise missiles"), stealth aircraft (such as the F - 117 - a, B - 2, F - 35, F - 22, etc.), high speed anti-radiation missile (e.g., AGM - 88), and other high performance of weapons and equipment, and create a surprise effect in all previous local war, great changes have taken place in modern warfare tactics. MIMO radar with its multiple input multiple output characteristics, an increase in space sampling, against stealth, electronic countermeasures and interference has a unique advantage. In this complicated situation, in order to find and attack before enemy first, ensure their survival ability, grasps the battlefield electromagnetic dominance, realize effective monitoring and prevent enemy target, more and more arduous tasks and challenges facing modern radar. Such as the radar should have the ability of detecting weak targets at a distance, the distance of stealth target detection ability. One more in need of radar system has a good bearing resolution, enemy target bearing quickly and accurately identify location, to implement precision. Therefore, the good performance of the direction to be one of the most important aspects of the MIMO radar system to detect target information.

DOA estimation (DOA, Direction-of-concatenated) is an important content of array signal processing, its applications in radar, communication, sonar, earthquake, exploration, radio astronomy and biomedical engineering, and many other military and civilian areas of the economy. DOA estimation is the use of a set in a certain way in different space position sensors for space source in time domain and the airspace samples at the same time, again by the sensor array analysis of sampling data processing to achieve the orientation of the source to the space to estimate. In DOA estimation, resolution, accuracy and robustness, speed, distinguish the target number of how many, etc., determine the bearing to estimate the performance of a good or bad [2-5].

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As a new multi-channel radar, MIMO technology using signal diversity and space diversity, greatly improving the radar signal processing system of degrees of freedom. In order to ensure the independence between the channel, each emission emitting signal of orthogonal to each other. MIMO radar by multiple transmitting array and multiple receiving array elements, thus for target, each transmitting array yuan incentive scattering field is division in different spatial location of the receive array yuan, at the same time, different location launch unit scattering field will received in the same position of overlay, arrays with matched filter to realize different emission signal sorting. These characteristics determine the performance of the MIMO radar space sampling issues involved in to improve has great potential. Independent of each other because of the MIMO radar at the same time increases the number of transmit and receive array yuan, for receiving and transmitting antenna combined two multiplied to produce more effective observation aperture, thus forming the equivalent observation aperture and spatial sampling density. By the DOA estimation theory, these features can improve the target direction estimation resolution and accuracy, and can be doubled the biggest distinguish the target number. Therefore, based on DOA estimation of MIMO technology research, has very important theoretical and practical significance. Compared with the traditional radar DOA estimation (DOA, Direction-of-concatenated) estimates, bistatic MIMO radar, bistatic MIMO radar) in the Direction of the vector is transmitting and receiving Direction vector Kronecker product, so the bistatic MIMO radar Angle estimation to estimate the DOA and wave Direction (DOD, Direction of departure), the traditional radar Angle estimation is complex, therefore, this paper puts forward Capon dimension reduction method of bistatic MIMO radar transceiver Angle estimation [6-8].

2. Bistatic MIMO Radar Model

Bistatic radar technology in the tactical radar has been underway for a certain application research, and the war now demand for radar and radar field survival ability of wave cut demand, coupled with the rapid development of the digital circuit technology, the bistatic radar technology is more and more attention in the LeiDaJie. The basic characteristics of bistatic radar is closed, equipment (including the antenna) separation, target and transceiver equipment located in the triangle plane. Compared with the single base radar, bistatic radar structural configuration than the structure of the single base radar configuration is more complex. In order to achieve a correct orientation to the target, in addition to the general bistatic radar single base of radar, signal and postscript signal processing function, also has received, sent between space and time and phase of the "three simultaneous" problem. First is received and sent synchronous scanning beam space. Due to the basic characteristics of bistatic radar, and long hair beam separation distances, so how do you ensure that in the process of scanning over the airspace, closed, hair beam irradiation to the same goal and at the same time has good data rate, this is a big technical problem. Second, how to send and receive equipment to provide a unified high precision time benchmark, this is the time synchronization problem. Time synchronization is completed bistatic radar ranging and beam scanning synchronization rely on premise. Again, for the characteristics of pulse compression, MTI, PD signal coherent processing of bistatic radar, also must ensure that the phase synchronization between sending and receiving devices [9-11].

The main characteristics of bistatic radar can be summarized as the following three aspects: (1) To receive, send equipment separation; (2) The received signal is the target of the backward scattering echo; (3) The relation between triangulation location. Formal based on the three characteristics of bistatic radar, led to bistatic radar on the tactical and technical performance has some unique advantages.

Conventional precision guidance radar using a narrow beam in order to obtain high measurement precision, search ability is often very weak, the launch of bistatic MIMO radar using a wide beam, using DBF technology at the same time when receiving the multi-beam, use for a long time accumulated technology make up for the loss of power. Both shorten the search time patterns, and to ensure the short period of time of multiple target tracking and high precision measurement, thus will greatly enhance the saturation attack resistance ability. At the same time, the bistatic MIMO radar can obtain targets at the same time relative to the sending and receiving array and sending and receiving array to the target distance and Angle information, has the characteristics of information surplus, and therefore has a unique ability to resist deception jamming. Analysis of bistatic MIMO radar signal model, array configuration is shown in Figure 1.

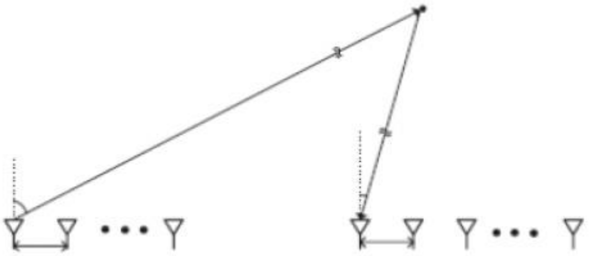

Figure 1. Dual-based MIMO Radar Array Configuration Diagram

This is an intensive transmitting antenna by the M and N-intensive receiver antenna composed of narrow-band dual-based MIMO radar system. Transmitter launch of M quadrature encoder signals for the transmitted signal vector $s(t)=\left[s_1(t),s_2(t),...,s_M(t)\right]^T$. Assuming that the aperiodic autocorrelation sidelobe of cross-related signal is very low, even if the Doppler shifts exist. Launch the encoding of the baseband signal is recorded as $s_m s_m{}^H \in C^{1\times K}$, m represents the m-th transmitted signal $s_m s_m{}^H = K$, the use of a binary sequences with zero correlation zone. And high Doppler frequency is still low in the zero correlation zone of the autocorrelation and cross-sidelobe. Doppler frequency is almost no effect on the orthogonality of the waveform, the waveform approximation retains the orthogonality of the target of large Doppler frequency. Doppler frequency caused by a variety of pulse can be ignored. Here, we assume that all targets located in an adjacent range, both the goal of zero correlation zone, so the targets within the sidelobe can be ignored. Suppose a target is located in the ¨ ¯ , which target the desired launch angle (defined as the DOD), to target the desired acceptance angle (defined as of DOA). Data received by the target launch to reach the receiver array can be expressed as the following expression:

$$
\begin{aligned}
Y_m &= a_r\left({}^{-} \right) a_t^T\left({}^{\ddot{}} \right)\begin{bmatrix} 0 \\ ... \\ \sqrt{K}e^{j2\text{®} f_d t_l} \\ ... \\ 0 \end{bmatrix} + \frac{1}{\sqrt{K}} Z s_m^H \\
&= a_r\left({}^{-} \right) a_{tm}\left({}^{\ddot{}} \right) \quad \sqrt{K}e^{j2\text{®} f_d t_l} + N_m
\end{aligned}
\tag{1}
$$

Which $N_m = \frac{1}{\sqrt{K}} Z s_m{}^H$,and $a_{tm}\left({}^{\ddot{}} \right)$ is m-th element in the launch of the array steering vector. $N_m \in C^{N\times 1}$ is defined as the m-th baseband transmit signals to match the filter noise vector, $(\bullet)^H$ is Hermitian transpose. In the case of P target (1) can be modified to:

$$
Y_m = A_r D_m \Phi + N_m \tag{2}
$$

Which $A_r = \left[a_r({}^{-}{}_1),...,a_r\left({}^{-}{}_p\right)\right]$

$$D_m = diag\left[a_{tm}\left(\text{¨}_1\right),\ldots,a_{tm}\left(\text{¨}_p\right)\right]$$

$$\Phi = \begin{bmatrix} {}_1\sqrt{K}\,e^{\,j2\text{®}\,f_{d1}t_l} \\ \ldots \\ {}_P\sqrt{K}\,e^{\,j2\text{®}\,f_{dP}t_l} \end{bmatrix}$$

It is assumed that the different objectives have different Doppler frequency, and all the P target in the same range interval.

3. Capon Down-Dimensional Method

3.1. Theoretical Analysis

Capon algorithm is the full name of Capon minimum variance algorithm. It USES part of the degrees of freedom form the main beam above the expected direction of the user, and at the same time with the rest of the degrees of freedom is formed on the interference signal in the direction of zero. Capon algorithm has the advantage of the noise and the contribution by any interference from the signal source direction of power to a minimum, but also can keep the signal power source direction remains the same. Capon algorithm has the characteristics of adaptive interference cancellation, and restricted by array geometry interference cancellation number resolution depends on the array geometry and signal-to-noise ratio, etc. Doa of double-base MIMO radar and wave direction Angle estimation are discussed, and an d Capon reduction algorithm is presented. This algorithm needs only one dimensional search, can avoid the two-dimensional Capon (2 d - Capon) algorithm is of high computation cost and can be very good proved that the algorithm in terms of performance is better than 2 d Capon algorithm has better [12-13].

Multiple input multiple output (MIMO) radar is to use multiple antennas at the same time legend diverse waveform in a similar way to accept the reflected signals at the same time. Wave from the Direction of the MIMO radar (DOD, Direction-of-departure) and DOA (DOA) has been carried on the thorough research. Two-dimensional Capon algorithm (2 d - Capon) is a kind of realization of MIMO radar DOA and DOD estimation algorithm; However, two-dimensional search demand higher computational complexity. Dimension reduction in double-base MIMO radar Angle estimation Capon algorithm, it obviously reduces the complexity.

Consider a double-base MIMO radar system: its transmitting array and receiving arrays are uniform linear array, there are m and n respectively adjacent orderly half wave transmitting array antenna spacing and receiving arrays. Additional assumptions have K non related target, through the output of the matched filter in the receiving end can be expressed as:

$$X=\left[a_r\left(\text{¤}_1\right)\otimes a_t\left(\text{¯}_1\right),a_r\left(\text{¤}_2\right)\otimes a_t\left(\text{¯}_2\right),\ldots,a_r\left(\text{¤}_K\right)\otimes a_t\left(\text{¯}_K\right)\right]B^T+W \quad (3)$$

Which ¯_K and ¤_K are K target normal emission arrays and array of launch angle and acceptance angle. $B \in C^{L\times K}$ Waveform caused by the Doppler frequency in the number of snapshots K target sources include phase and amplitude, and the magnitude of the main subject, such as reflection coefficient of the transmit gain and receive gain, path fading and other losses.

$$a_r\left(\text{¤}_k\right)=\left[1,\exp(-j\text{®}\sin\text{¤}_k),\ldots,\exp\left(-j\text{®}\left(N-1\right)\sin\text{¤}_k\right)\right]^T$$

$$a_t\left(\text{¯}_k\right)=\left[1,\exp(-j\text{®}\sin\text{¯}_k),\ldots,\exp\left(-j\text{®}\left(M-1\right)\sin\text{¯}_k\right)\right]^T$$

$a_r\left(\text{¤}_k\right)$ and $a_t\left(\text{¯}_k\right)$ are respectively receive steering vector ¤_k and transmit steering vector ¯_k. W is to receive receives an additive white Gaussian noise matrix. $\otimes$ indicates plot for Kronercker.

For the signal model (3), we can see that the covariance matrix R_x can be the origin of estimated by $R_x = XX^H / L$, so we can construct two-dimensional Capon spatial spectrum:

$$f_{capon}(¤,¯) = \frac{1}{\left[a_r(¤) \otimes a_t(¯)\right]^H R_x^{-1} \left[a_r(¤) \otimes a_t(¯)\right]} \tag{4}$$

Here, the K peak of $f_{capon}(¤,¯)$ is the target DODs and DOAs. The two-dimensional Capon requires a detailed two-dimensional search, due to the high computational cost, the efficiency of doing so is relatively low.

3.2. Capon Down-dimensional Method

Definition:

$$V(¤,¯) = [a_r(¤) \otimes a_t]^H R_K [a_r(¤) \otimes a_t]$$

It can also be expressed as:

$$\begin{aligned} V(¤,¯) &= a_t(¯)^H \left[a_r(¤) \otimes I_M\right]^H R_x^{-1} \left[a_r(¤) \otimes I_M\right] a_t(¯) \\ &= a_t(¯)^H Q(¤) a_t(¯) \\ Q(¤) &= \left[a_r(¤) \otimes I_M\right]^H R_x^{-1} \left[a_r(¤) \otimes I_M\right] \end{aligned} \tag{5}$$

Equation (5) is a quadratic optimization problem. In order to eliminate the zero solution, we also consider constraints $e_1^T a_t(¯) = 1$ to have been joined, here $e_1 = [1, 0, ..., 0]^T$. This optimization problem, we can use the linear constraint minimum variance to rebuild, get:

$$\min_{¤} a_t(¯)^H Q(¤) a_t(¯), s.t. e_1^T a_t(¯) = 1 \tag{6}$$

Using the Lagrange multiplier, then Equation (6) becomes:

$$\hat{¤} = \arg\min_{¤} \frac{1}{e_1^T Q(¤)^{-1} e_1} = \arg\max_{¤} e_1^T Q(¤)^{-1} e_1 \tag{7}$$

And then search $\phi \in [-90°, 90°]$, you can get $Q(¤)^{-1}$ the K largest peaks of each element (1,1). K largest peaks correspond to the requirements bistatic MIMO radar direction of arrival (DOA).

On Equation (5), you can also consider this:

$$\begin{aligned} V(¤,¯) &= a_r(¤)^H \left[I_N \otimes a_t(¯)\right]^H R_x^{-1} \left[I_N \otimes a_t(¯)\right] a_r(¤) \\ &= a_r(¤)^H P(¯) a_r(¤) \\ P(¯) &= \left[I_N \otimes a_t(¯)\right]^H R_x^{-1} \left[I_N \otimes a_t(¯)\right] \end{aligned} \tag{8}$$

Similarly, using the Lagrange multiplier, so the solution becomes:

$$\hat{¯} = \arg\max_{¯} e_2^T P(¯)^{-1} e_2 \tag{9}$$

$e_2=\left[1,0,...,0\right]^T \in R^{N\times 1}$. Searchθ ∈ $[-90°, 90°]$, we can get the K maximum peak of $P\left(\bar{\ }\right)^{-1}$ (1,1) element, which is corresponding to the double base MIMO radar waves away from the direction (DOD).

Bistatic MIMO radar Capon algorithm based on DOD and DOA estimation of dimensionality reduction algorithm main steps:

1) covariance matrix R_x;

2) ¤ , $Q\left(¤\right)^{-1}$ ‘s (1,1) Each element of the K largest peaks are obtained by (7), which can be double base MIMO radar DOA estimates;

3) $\bar{\ }$, by (9), $P\left(\bar{\ }\right)^{-1}$ ‘s (1,1) element of K largest peak are obtained, which corresponds to DOD estimates.

4. Simulation of Experimental Tests

The same bistatic MIMO radar, sending and receiving arrays are half wavelength range of equidistant linear array, only the transmitting array into M = 8, to receive the array of N = 8. Emission the orthogonal Hardmard code waveform at the transmitter, sensor, and signal to noise ratio for the SNR = 10 dB, the number of snapshots L = 100. If we assume that there are four goals in the space $\left(\ddot{\ }_1,\bar{\ }_1\right)=\left(-10^\circ,-20^\circ\right)$ $\left(\ddot{\ }_2,\bar{\ }_2\right)=\left(10^\circ,30^\circ\right)$ $\left(\ddot{\ }_3,\bar{\ }_3\right)=\left(40^\circ,-30^\circ\right)$ $\left(\ddot{\ }_4,\bar{\ }_4\right)=\left(-40^\circ,50^\circ\right)$ this is the case under the simulation of W with zero mean Gaussian white noise. And we make the signal to noise ratio changes from 5dB and 10dB to 30dB, interval 5dB. 100 Monte Carlo experiments to define the angle estimated mean square error (RMSE) as follows:.

$$RMSE=\sqrt{\frac{1}{Lc}\sum_{m=1}^{Lc}\left|\,{}_0-\hat{\ }\,\right|^2} \tag{10}$$

Where Lc is the number of Monte Carlo experiments.

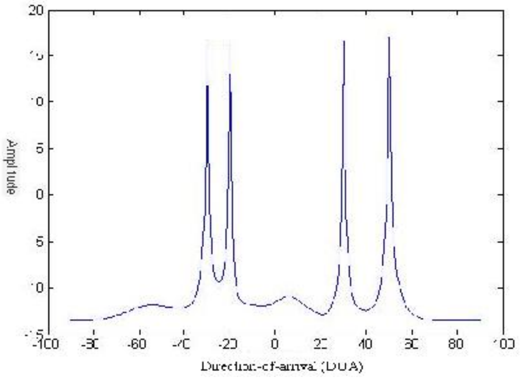

Figure 2. Direction of Arrival (DOA)

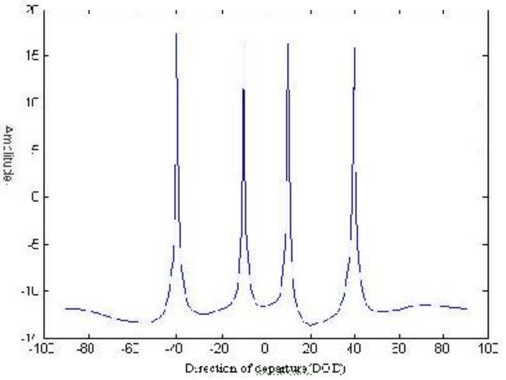

Figure 3. Direction of Departure (DOD)

Figure 2 and Figure 3 is the algorithm of the four goals in double-base MIMO radar DOA estimate and DOD. Two figure of wave can clearly see the value of the DOD and DOA. This shows that in the case of gaussian white noise, the method can effectively realize the multi-objective Angle joint estimation.

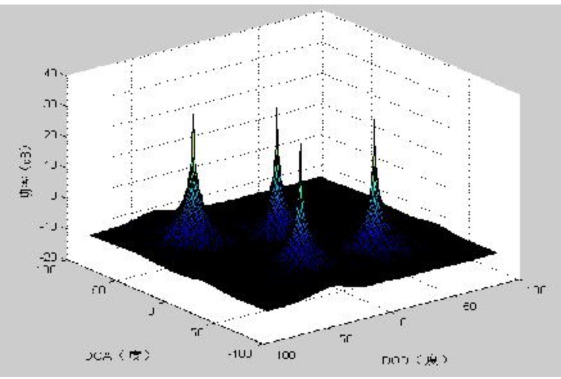

Figure 4. Joint Estimation of DOA and DOD

Above are our four algorithms of double-base MIMO radar target estimate DOA and DOD. This Figure 4 wave can clearly see the value of the DOD and DOA. Figure 5 for the method of four matches the DOD and DOA value perspective.

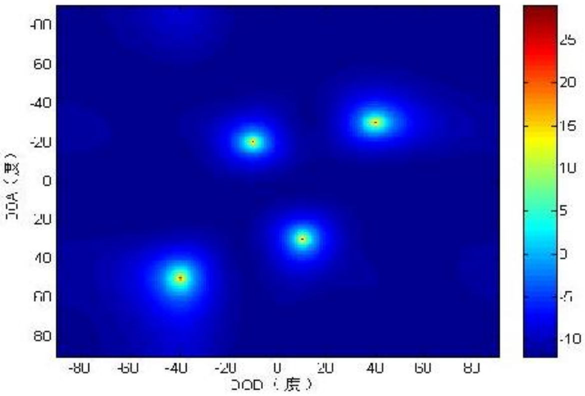

Figure 5. Angle Search

5. Conclusion and Outlook

This paper mainly studies based on phased array system coherent bistatic MIMO radar multi-target direction finding, the main characteristics by lightning is cloth station spacing is small, multiple transmit and receive array yuan to the target approximate parallel rays, target relative to the sending and receiving arrays have the same DOA, and for the narrowband signal, array yuan between envelope delay can be ignored. In this paper, the doa of double-base MIMO radar and wave direction Angle estimation are discussed, and an d Capon reduction algorithm is presented. The proposed algorithm needs only one dimensional search, can avoid the two-dimensional Capon (2 d - Capon) algorithm of high computational cost, and can be very good to prove the algorithm in terms of performance is better than two dimensional Capon algorithm.

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