Prediction of Performance: Practicality between MIMO and Collocated MIMO Radar

K. M. S. Sagar Madan, D. S. Samba Siva Rao

Abstract-We recommend a novel method for multiple-input multiple-output (MIMO) radar with colocated antennas which we call phased-MIMO radar. The core of the projected method is to panel the broadcast array into a number of sub arrays that are permissible to overlie. Then, each subarray is worn to articulately put on the air a waveform which is orthogonal to the waveforms transmitted by additional subarrays. A***rticulate processing gain can be achieved by designing a weight vector for each subarray to form a beam towards a certain direction in space. Moreover, the subarrays are shared in cooperation to form a MIMO radar ensuing in elevated lanky oath capabilities. Substantial improvements offered by the proposed phased-MIMO radar technique as compared to the phasedarray and MIMO radar techniques are verified systematically and by simulations from beginning to end analyzing the analogous grin patterns and the practicable output signal-to-noise-plus-interference ratios. Both analytical and simulation results validate***d and shown in MATLAB platform about ***the effectiveness of the proposed phased-MIMO radar.***

Keywords: MIMO, Radar, Phase, subarrays.

I. INTRODUCTION

Despite more than a hundred-year history, radar is still a vital research area. Recently, a new concept of radar named Multiple-Input Multiple-Output. (MIMO) radar emerged and received considerable attention. The recent work indicates that MIMO radar has the potential to outperform the conventional radar systems. In this chapter, in order to help understanding the work presented in the rest of the thesis, the basic but important terminologies and concepts in radar are clarified and some fundamentals of array signal processing are briefy described first. Then, the recent work in MIMO radar is introduced, which leads to the main subject of this thesis: multi-target localisation in MIMO radar. The basic functions of radar are detection, parameter estimation and tracking [1], [2]. The most fundamental one among these functions is detection. Detection is the process of determining whether the received signal is an echo returning from a desired target or consists of noise only. The success of the detection process is directly related to SNR at the receiver and the ability of the radar to separate desired target echoes from unwanted reflected signals. So, various techniques are developed to maximize the SNR at the output of the receiver and to increase the ability of the radar to separate targets from unwanted echoes and interference. After the detection process if it turns out that a target really exists, several parameters of the target like range, velocity and angle of arrival should be estimated from the received signal.

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The choice of the radar transmit waveform is a major contributor to the resolution of these parameters. Many types of waveforms can be found in the literature ([5], [6]), that improve the resolution of those parameters or other radar system performance metrics. After localization of a target radar can provide a target's trajectory and track it by predicting where it will be in the future by observing the target over time and using dedicated filters. Some types of radar can perform more specialized tasks in addition to these basic functions. One of these tasks performed by more recent radars is imaging. High resolution two or three dimensional maps of ground can be constructed by using this new technology. Different types of antennas, transmitter, receiver structures and processing units are employed in radars according to their functions and on which platform the radar is located. The separation of antennas is also determined by radar's function. Conventional radar systems can be classified into three groups based on the number of antennas the system has and the distance between them. These are called monostatic, bistatic and multistatic systems [1]. Majority of radar systems are monostatic. In monostatic systems, transmitter and receiver antennas are co-located and usually there is only one antenna performing both transmitting and receiving tasks in a time multiplexed fashion. In bistatic systems, there are one transmitter and one receiver antenna, but they are significantly separated [2]. Multistatic radar systems have two or more transmitting or receiving antennas with all antennas separated by large distances when compared to the antenna sizes [3]. Recently, a new field of radar research called Multiple Input Multiple Output (MIMO) radar has been developed, which can be thought as a generalization of the multistatic radar concept. MIMO radar has multiple transmit and multiple receive antennas as its name indicates [9]. The transmit and receive antennas may be in the form of an array and the transmit and receive arrays can be co-located or widely separated like phased array systems. Although some types of MIMO radar systems resemble phased array systems, there is a fundamental difference between MIMO radar and phased array radar. The difference is that MIMO radar always transmits multiple probing signals, via its transmit antennas, that may be correlated or uncorrelated with each other, whereas phased array radars transmit scaled versions of a single waveform which are fully correlated. The multiple transmit and receive antennas of a MIMO radar system may also be widely separated as radar networks. The fundamental difference between a multistatic radar network and MIMO radar is that independent radars that form the network perform a significant amount of local processing and there exists a central processing unit that fuses the outcomes of central processing in a reasonable way. For example, every radar makes detection

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decisions locally then the central processing unit fuses the local detection decisions. Whereas MIMO radar uses all of the available data and jointly processes signals received at multiple receivers to make a single decision about the existence of the target. The key ideas of MIMO radar concept has been picked up from MIMO communications. MIMO is a technique used in communications to increase data throughput and link range without additional bandwidth or transmit power. This is achieved by higher spectral efficiency and link reliability or diversity. Using MIMO systems in communications made significant improvements when there is serious fading in the communication channel. Radar systems also suffer from fading when there are complex and extended targets. Researchers took the idea of using multiple transmit and receive antennas to overcome the effects of fading from communications and applied it in the field of radar to achieve performance improvements.

II. PHASED ARRAY RADAR

Phased Array Radar uses antenna arrays for transmitting and receiving signals. These arrays may be linear or planar. In both the linear and planar arrays the separation between the elements is usually uniform. These arrays may be co-located and even transmit and receive functions can be performed by the same array. The two arrays may also be widely separated allowing the radar system to operate in bistatic mode. An example configuration of a phased array radar system is given in

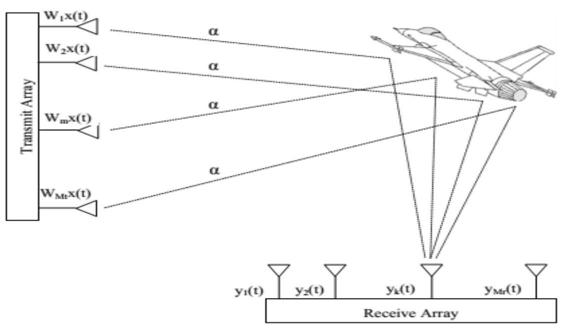

Fig. 3.0 Phased Array Radar Configuration

Since the interelement spacing of phased array radar antennas is small, the bistatic RCS seen by every transmit-receive pair in a phased array radar system is assumed to be the same. In phased array radars, every antenna element of the transmit array sends a scaled version of the same waveform. Although the elements usually being omnidirectional, by properly adjusting these scale factors, a directive antenna with a high gain can be obtained. By changing these scale factors in time, a beam can be steered in space toward any desired direction similar to a conventional radar with a directional antenna. The process of scaling waveforms can be also performed on the signals received by the received elements. This makes the effect of using a directional antenna at the receiver. This process of scaling waveforms at the transmitter and receiver is known as beamforming. That is why phased array radars are also called beamformers. Since this beamforming process is performed electronically, the look direction of the array may change very fast and the region of interest can be searched very rapidly without any mechanical movement. This is the main advantage of phased array radar systems. The number of elements in an array may be large enough allowing steering multiple independent beams at once. These beams may be used to track multiple targets or search different areas of the space simultaneously. Search and track operation may be also performed in a time multiplexed fashion by the same radar system allowing the use of phased array radar system as multi-function radar. Besides these advantages, its complexity, difficulties in the production stages of phased array antennas and high cost are its main disadvantages.

III. PHASED-MIMO RADAR

Phased MIMO radar is a new concept which tries to bring superior aspects of both phased array and MIMO radar together in a single radar system. This radar system employs transmit and receive arrays which has closely spaced antenna elements like Coherent MIMO radar. Transmit array is partitioned into a number of subarrays that are allowed to overlap. Each subarray coherently transmits waveforms and performs beamforming towards a certain direction in space. By this way a coherent processing gain can be achieved like a phased array radar system. Waveforms transmitted by every transmit subarray are orthogonal to each other to achieve advantages of waveform diversity like a MIMO radar system. The advantages of phased-MIMO radar system can be summarized as:

- It benefits from all advantages of the MIMO radar i.e. improved angular resolution and parameter identifiability, detecting a higher number of targets.
- It enables the application of conventional beamforming techniques at both transmitter and receiver.
- It offers improved robustness against strong interference.
- It offers a tradeoff between angular resolution and robustness against beamshape loss.

To provide a better understanding, the transmit array structure of phased-MIMO radar is given in Figure below.,

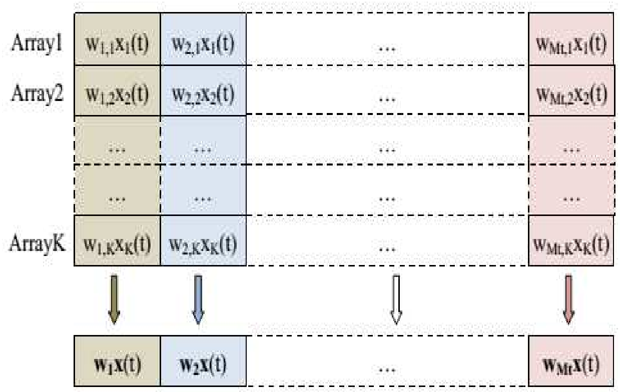

Fig. 4.0 Transmit Array Structure of Phased-MIMO Radar

In the figure a transmit array of elements and K subarrays is shown. Each transmit element belongs to at least one subarray. Each subarray may contain from one element up to elements and in general no two subarrays

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overlap completely. If a weight coefficient is equal to zero, it means that the transmit element does not belong to subarray. The nonzero weight coefficients of a subarray scales the same waveform to form and steer a beam in space and the waveforms are orthogonal.

IV. ROBUST BEAMFORMING

The beamformer is used to extract the information from some angle of interest while suppressing the unwanted signal impinging from other angles. An adaptive beamformer uses the second order statistics of the received signal to maximize the SINR (signal to noise plus interference ratio) at the receiver. To maximize the SINR, one can minimize the total variance while maintaining the signal response to be unity. This beamformer is called minimum-variance distortionless response (MVDR) beamformer. The MVDR beamformer has the highest SINR among all the beamformers. However, it is very sensitive to the direction of arrival (DOA) mismatch. If there is a mismatch in DOA, the MVDR beamformer misinterprets the signal of interest as a source of interference and suppresses it. This effect is called self-cancelation and it greatly reduces the SINR. The virtual array formed in MIMO radar can be much larger than the physical receiving array in SIMO radar. A longer receiving array is more prone to suffer from the self-cancelation effect. Therefore the robustness of the beamformer is very important in MIMO radar. To improve the robustness of the beamformer, many approaches have been proposed, including diagonal loading methods linear constraint based methods quadratic constraint methods, Bayesian methods and convex set methods. The complexity of the proposed algorithm is the same as the MVDR beamformer but the proposed algorithm is much more robust against DOA mismatch.

V. MVDR BEAMFORMER

Consider a uniform linear array (ULA) of N omni directional sensors with interelement spacing d. The signal of interest (SOI) is a narrowband plane wave impinging from angle θ. The baseband array output y(t) can be expressed as

$$\mathbf{y}(t) \;=\; x(t)\mathbf{s}(\theta) + \mathbf{v}(t), \tag{1}$$

where v(t) denotes the sum of the interferences and the noises, x(t) is the signal of interest (SOI), and s(θ) represents the baseband array response of the SOI. It is called steering vector and can be expressed as

$$\mathbf{s}(\theta) \;\triangleq\; \begin{pmatrix} 1 & e^{j\frac{2\pi}{\lambda}d\sin\theta} & \cdots & e^{j(N-1)\frac{2\pi}{\lambda}d\sin\theta} \end{pmatrix}^T, \tag{2}$$

where λ is the operating wavelength. The output of the beamformer can be expressed as $w^{\dagger}y(t)$, where w is the complex weighting vector. The output SINR (signal-to-interferences-plus-noise ratio) of the beamformer is defined as

$$\text{SINR} \triangleq \frac{E|x(t)\mathbf{w}^{\dagger}\mathbf{s}(\theta)|^2}{E|\mathbf{w}^{\dagger}\mathbf{v}(t)|^2} = \frac{\sigma_x^2|\mathbf{w}^{\dagger}\mathbf{s}(\theta)|^2}{\mathbf{w}^{\dagger}\mathbf{R_v}\mathbf{w}}, \tag{3}$$

The solution to this problem is well-known and was first given by Capon in

$$\mathbf{w}_c = \frac{\mathbf{R_y}^{-1}\mathbf{s}(\theta)}{\mathbf{s}^{\dagger}(\theta)\mathbf{R_y}^{-1}\mathbf{s}(\theta)}. \tag{4}$$

This beamformer is called minimum variance distortionless response (MVDR) beamformer in the literature. When there is a mismatch between the actual arrival angle θ and the assumed arrival angle θm, this beamformer becomes

$$\mathbf{w}_m = \frac{\mathbf{R_y}^{-1}\mathbf{s}(\theta_m)}{\mathbf{s}^{\dagger}(\theta_m)\mathbf{R_y}^{-1}\mathbf{s}(\theta_m)}. \tag{5}$$

Therefore this method can always force the gains at a desired range of angles to exceed a constant level while suppressing the interferences and noise. A closed form solution to the proposed minimization problem is introduced, and the diagonal loading factor can be computed systematically by a proposed iterative algorithm. Numerical examples show that this method has an excellent SINR performance and a complexity comparable to the standard MVDR beamformer.

VI. OUTPUTS

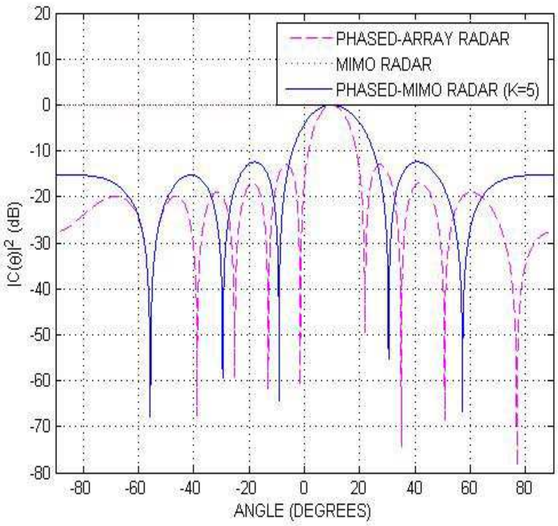

Fig. 5 C (θ) Vs Angle (Degrees)

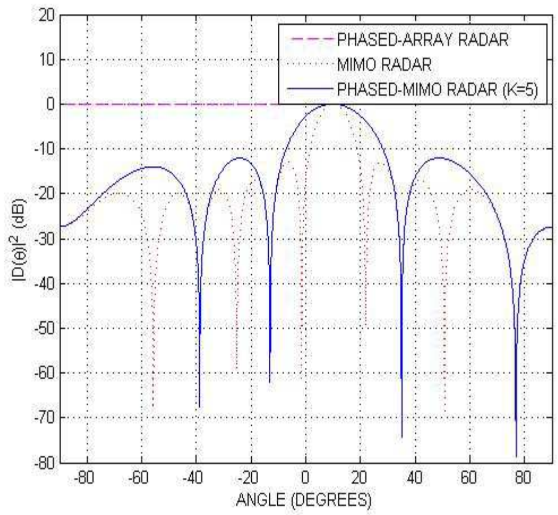

Fig. 6 D (θ) Vs Angle (Degrees)

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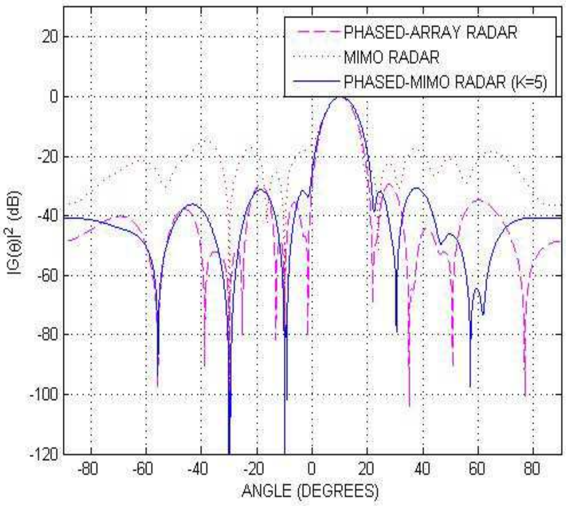

Fig. 7 G (θ) Vs Angle (Degrees)

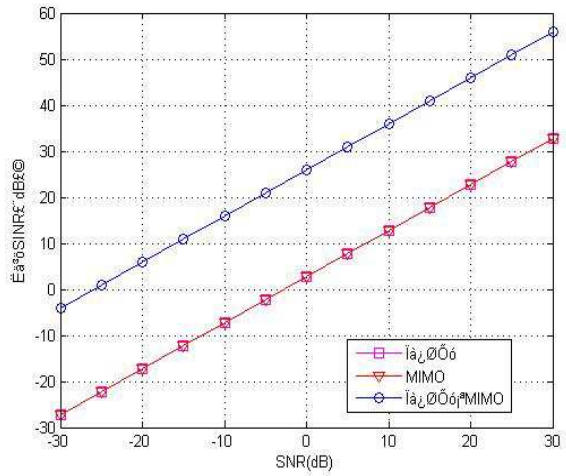

Fig. 8 SNR

VII. CONCLUSION

A new technique for MIMO radar with colocated antennas has been proposed. This technique is based on partitioning the transmit array to a number of subarrays which are allowed to overlap. Each subarray is used to coherently transmit a waveform which is orthogonal to the waveforms transmitted by other subarrays. It will be shown that the proposed technique combines the advantages of the phased-array and MIMO radars and, therefore, it has a superior performance. The Simulations will be done in matlab perform and the results are shown effectively. Throughout this thesis, several proposed approaches have shown their abilities to improve the multi-target localisation of MIMO radar in di§erent cases. In the case of the spatial signal model, the proposed multi-target parameter estimation approach based on the virtual array structure has the ability to break through the identiÖability limitation of the conventional radar system while the existing methods such as Capon, APES and subspace methods cannot. Although the LS method has the ability to exceeding the identiÖability limitation, the virtual array based multi-target parameter estimation approach shows the signiÖcant superiority over the LS method in the estimation accuracy of the parameters related to the multiple targetsílocations which are DOAs and the path gains. Then, the proposed spatiotemporal signal model extended the application of these existing multi-target parameter estimation methods from the spatial only signal model to the spatiotemporal signal model in which the relative delays of targets has been taken account of. However, it was observed that, in both the spatial only and spatiotemporal model, the mutual interferences among the targets severely degrades the accuracy of multi-target parameter estimation when the targets are close together. The proposed interference suppressed optimization has well addressed the problem of these mutual interferences. Based on the solutions to the interference suppressed optimisation, the two proposed multi-target parameter estimation algorithms obviously improve the estimation accuracy of the parameters for multiple targetsí locations comparing to the existing methods which only treat the interferences as ìnoiseî. The proposed one-dimensional iterative algorithm avoids the need for multidimensional search but the initial estimates are required. Compared with the one-dimensional iterative algorithm, the proposed multidimensional optimal algorithm provides better parameter estimates but with high computational complexity due to the multidimensional search. The BBO approach applied in the multidimensional optimal algorithm signiÖcantly reduces its computational complexity.

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