TRANSMITS BEAMFORMING AND RECEIVER DESIGN FOR MIMO RADAR

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Abstract - Beamforming is a marriage between the antenna technology and digital technology. This is achieved by combining elements in a phased array in such a way that signals at particular angles experience constructive interference while others experience destructive interference in recent years there has been growing interest in a new class of radar systems employing multiple transmit antennas fed by different waveforms. This Paper describe the method of transmits beamforming design for MIMO radar. Transmit beamforming in MIMO radar based on the design of multiple correlated waveforms have been proposed. This Project points out that this approach couples the spatial and temporal parts of the problem due to multiple correlated waveforms and significantly complicating the design. It is shown here that the most general form of transmit beamforming can be achieved in a decoupled form, using orthogonal (uncorrelated) waveforms and MVDR Beamforming weights. This formulation allows the use of standard beamformer design procedures. Examples are provided to illustrate the design of beamformers for search and tracking applications. The examples include single and multiple beamformers using proposed techniques, these examples are illustrated by simulation results

Key Words: Signal model, Match filter design, Beamforming design

1. INTRODUCTION

Compared to phased-array, multiple-input multiple-output (MIMO) radars provide more degrees-of freedom (DOF) that can be exploited for improved spatial resolution, better parametric identifiability, lower side-lobe levels at the transmitter/receiver, and design variety of transmit beampattern. Multiple-input multiple-output (MIMO) radars allow each transmitting antenna to transmit independent waveforms and thus provide extra degrees-of-freedom (DOF) that can be exploited to improve system performance. In this paper we present a different approach based on a reformulation of the problem which separates in a natural way the spatial and temporal parts of the design. This separation provides clearer insight into the transmit beamformer design and reveals the close connections to previous work on beam pattern synthesis and multi-rank beamformers. It also enables the application of well-known methods to the MIMO transmit beamformer design.

The structure of the paper is as follows. In Section 2 problem formulation and previous work, section 3 we describe the Signal model, section 4 Match filter design, section 5 Simulation result and section 6 contains brief conclusion and future scope.

2. PROBLEM FORMULATION AND PREVIOUS WORK :

Most of the work on MIMO radar considers using a set of uncorrelated transmits waveforms. However, using correlated waveforms has also been studied, especially in the context of transmit beamforming. The recent work on transmit beamforming for MIMO radar focuses on the design of the correlation matrix of the signals at the inputs of the array elements. This formulation of the problem couples the spatial (beamformer) and temporal (waveform) parts of the problem, significantly complicating the design. It leads to a solution requiring numerical optimization of a specified cost function which provides little insight into the problem. The problem considered in this paper is to transmit uniform power at a number of given target locations and minimize in all other locations. This is also called beampattern matching. To achieve this uniform linear array of N_T antenna elements with half-wavelength inter-element spacing is used. Let x_q (n) be the baseband transmitted signal from antenna q at time index n. The baseband received signal at spatial location θ_k can be written as

$$r_k(n) = \sum_1^{Nt} e^{-j(q-1)\pi\sin(\theta_k)x_q} \; n \quad n = 1,2, \ldots \ldots \ldots . N \qquad (1)$$

Where N is the total number of transmitted symbols. By defining

$$(\theta_d) = [\, 1 \quad e^{j\pi\sin(\theta_d)} \ldots \ldots \ldots . e^{j\pi(n_T-1)\sin(\theta_d)} \,]^T \qquad (2)$$

And transmits steering vector is given by

$$x(n) = [x_1(n) \;\; x_2(n) \; \ldots \ldots . x_{nt}(n)]^T \qquad (3)$$

A vector of transmitted symbols, the received signal in (1) can be written as

$$r_k(n) = a_T^H(\theta_k)x(n) \tag{4}$$

Following (2), the power received at location θ_k can be written as

$$p(\theta_k) = a_T^H(\theta_k)\, R\, a_T(\theta_k) \tag{5}$$

Where R is the covariance matrix of the waveforms. In order to achieve the desired beampattern, an appropriate covariance matrix R has to be found. The matrix R can be optimized by minimizing the difference between the desired and designed values of the beampattern. However, as mentioned in the introduction, the matrix R should be a positive semi-definite and all of its diagonal elements must be equal. The performance of these algorithms compared to synthesizing the covariance matrix is poor. They have lower role-off in the transition band and do not guarantee equal average power constraint.

3. PRAPOSED TECHNIQUES

3.1 Principle

Here we take a more traditional point of view involving beamformer design rather than signal design. We assume, as was discussed in Section III that the transmitted signals $s_n(t)$ are obtained by passing a set of orthogonal $\tilde{s}_n(t)$signals through complex beamformer weights w_n. Once we replace the signals $s_n(t)$ by the orthogonal signals $\tilde{s}_n(t)$ and the beamformer weights w_n, the signal correlation matrix Rs becomes independent of the waveforms being transmitted. The problem of designing the transmit beam pattern now involves designing a set of N_T (or fewer) beamformer weight vectors w_n. Thus, the system designer is free to select the transmitted waveforms based on their delay-Doppler properties, subject only to the requirement of orthogonality. Next note that the beam pattern $P_T(\theta)$ decomposes into a sum of N_T beam patterns.

$$\begin{aligned} P_T(\theta) &= a_T(\theta)^H W^* W^T a_T(\theta) \\ &= \sum_{n=1}^{N_T} a_T(\theta)^H W_n^* W_n^T a_T(\theta) \\ &= \sum_{n=1}^{N_T} P_{T,n}(\theta) \end{aligned} \tag{6}$$

In other words, the most general transmit beam pattern is the sum of 1 < M < N_T beam patterns of conventional beamformers. In the following we refer to the transmit beamformer defined in as a rank M beamformer.

3.2 Working Operation

In the traditional phased array radar, the system can only transmit scaled versions of a single waveform. Because only a single waveform is used, the phased array radar is also called SIMO (single input multiple-output) radar in contrast to the MIMO radar. The MIMO (multiple-input multiple-output) radar system allows transmitting orthogonal (or incoherent) waveforms in each of the transmitting antennas. These waveforms can be extracted by a set of matched filters in the receiver. Each of the extracted components contains the information of an individual transmitting path. There are two different kinds of approaches for using this information. First, the spatial diversity can be increased. In this scenario, the transmitting antenna elements are widely separated such that each views a different aspect of the target. Consequently the target radar cross sections (RCS) are independent random variables for different transmitting paths. Therefore, each of the components extracted by the matched filters in the receiver contains independent information about the target. Since we can obtain multiple independent measurements about the target, a better detection performance can be obtained. Second, a better spatial resolution can be obtained.

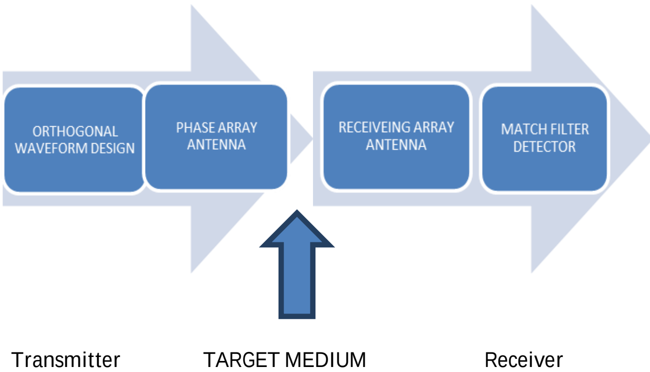

Fig-1 Basic Blockdiagram

In this scenario, the transmitting antennas are colocated such that the RCS observed by each transmitting path are identical. The components extracted by the matched filters in each receiving antenna contain the information of a transmitting path from one of the transmitting antenna elements to one of the receiving antenna elements. By using the information about all of the transmitting paths, a better spatial resolution can be obtained.

4. SIGNAL MODEL

Consider MIMO radar employing N_T antennas at the transmitter and N_R antennas at the receiver. We assume that the array aperture is sufficiently small so that the radar return from a given scatterer is fully correlated across the array. To simplify the presentation we assume that the two arrays are collocated. The arrays are characterized by the array manifolds: $a_R(\theta)$ for the receive array and $a_T(\theta)$ for the transmit array, where θ is the direction relative to the array. We assume that the arrays and all the scatterers are in the same 2-D plane. The extension to the 3-D case is straightforward and all of the following results hold for that case as well. The baseband representation of the radar returns from a single scatterer at direction θ_0 and delay T_0 relative to the radar is given by

$$x(t) = a_R(\theta_o)a_T(\theta_o)^T\sqrt{E_s}(t-T_o)h_0e^{i\omega_0 t} + V(t) \quad (7)$$

where x(t) is the N_R ×1 vector of the receive array outputs at time t, s(t) is a N_T × 1 vector of the transmitted signals at the different transmit antennas, h_0 is the amplitude of the scatterer, and ω_0 is the Doppler shift associated with it. The transmitted signal vector s (t) is normalized to have unit total energy, and the scale factor E represents the total transmit energy. Consider next the case where the transmitted signal s(t) is generated as a linear combination of a set of orthogonal signals ˜s(t), i.e.,

$$S(t) = W\tilde{s}(t) \quad (8)$$

Where $\tilde{s_n}(t)$ is an N_T × 1 vector and Wis an N_T × N_T matrix of complex weights. The columns $w_n$of W can be considered to be complex beamformer weight vectors, so that

$$S(t) = \sum_{n=1}^{N_T} W_N\ \tilde{s_n}(t) = W\ \tilde{S}(t) \quad (9)$$

Where $\tilde{s_n}(t)$ is the n[th] element of the vector $\tilde{s}(t)$and

$$W = [w_1 \ldots\ldots\ldots w_{N_T}] \quad (10)$$

In other words, each of the orthogonal signals $\tilde{s_n}(t)$is fed to the antennas through a beamformer w_n. This is sometimes referred to as beamspace MIMO to distinguish it from element space MIMO where the signals ˜s(t) are fed directly to the antenna elements.

Let Rs be the transmit signal correlation matrix defined as

$$R_S = \int_0^T S^*(t)\ S^T(t)dt \quad (11)$$

It follows that the weight matrix W is a matrix square root of the correlation matrix where

$$R_S = W^*W^T \quad (12)$$

The transmitted signal vector s(t) as well as the orthogonal waveform vector ˜s(t) are normalized to have unit energy. This implies that the weight matrix must obey the trace constraint

$$\{W\ W^H\} = 1 \quad (13)$$

The received signal x (t) (1) can now be written as

$$x(t) = \sqrt{E}a_R(\theta_o)a_T(\theta_o)^T W\tilde{s}(t-T_o)h_0e^{i\omega t} + v(t) \quad (14)$$

4. MATCH FILTER DESIGN

The received signal vector is assumed to be processed by a bank of matched filters, each matched to one of the waveforms$\tilde{s_n}(t)$. The output of the n[th] matched filter "tuned" to delay T and Doppler ω is

$$Z_n(T,\omega) = \int_0^T x(t)\ \tilde{s_n}(t-T_o)^* e^{-j\omega t}\ dt$$

Or

$$Z_n(T,\omega) = \sqrt{E}a_R(\theta_o)a_T(\theta_o)^T W\int_0^T \tilde{s}(t-T_o)\ X\tilde{s_n}(t-T)e^{-j(\omega-\omega_o)t}dt \quad (15)$$

In the rest of this paper we assume that the matched filter is perfectly tuned to the Doppler and delay of the scatterer, i.e., that $T = T_0$ and $\omega=\omega_0$. Using this fact and the orthogonality of the waveforms $\tilde{s_n}(t)$

$$\int_0^T \tilde{s}\ (t-T_0)\tilde{s}(t-T_0)^H dt = \int_0^T \tilde{s}\ (t)\ \tilde{s}(t)^H = I \quad (16)$$

The output of match filter can be written as

$$Z_n = \sqrt{E}a_R(\theta_o)a_T(\theta_o)^T W_n + u_n \quad (17)$$

It should be emphasized that the result above holds only when the matched filter is perfectly tuned to the Doppler and delay of the scatterer in which case the signals all have the same Doppler and delay shifts. Orthogonality is, of course, lost under general delay and Doppler shifts. We note also that the results do not change significantly when the transmitted signals are not perfectly orthogonal in which case (11) holds only approximately, as long as the cross correlation is smaller than the effect of the measurement noise.

5. RESULT AND SIMULATION

Construct a 16–element, half-wavelength-spaced line array. Choose two arrival directions of interest — one at 30° and the other at 45° azimuth. Assume both having 0° elevation. Specify a sensor spatial covariance matrix that contains signals arriving from –60° and 60° and noise at –10 dB.

Table-1 :Parameter

Parameter	Value
No. Of transmitting elements N_T	16
No. Of Receiving elements N_R	16
Noise power	-10dB
Array element Spacing d	0.5
DOA Azimuth angle	30^0 ,45^0
Elevation angle	0^0
Subcarrier spacing	250KHz
Random binary Digit	94

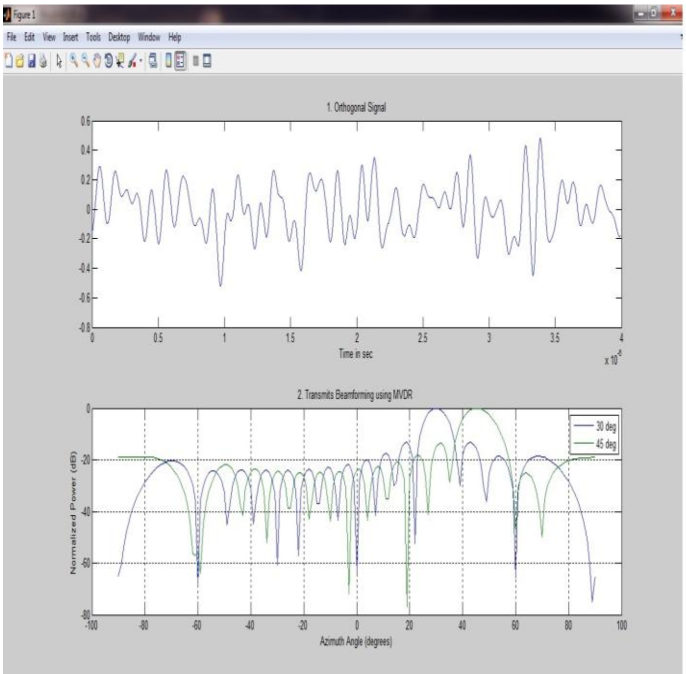

Figure 2: Transmits beamforming using uncorrelated waveform N_T=16 azimuth angle 30^0 and 45^0

The figure 2 shows plots for each beamformer direction. One plot has the expected maximum gain at 30° and the other at 45°. The nulls at –60° and 60° arise from the fundamental property of the Beamformer in suppressing power in all directions except for the arrival direction.

Figure 3 Construct a 16–element, half-wavelength-spaced line array. Choose two arrival directions of interest — one at 10° and the other at 20° azimuth. Assume both having 0° elevation. Specify a sensor spatial covariance matrix that contains signals arriving from –60° and 60° and noise at –10 dB.

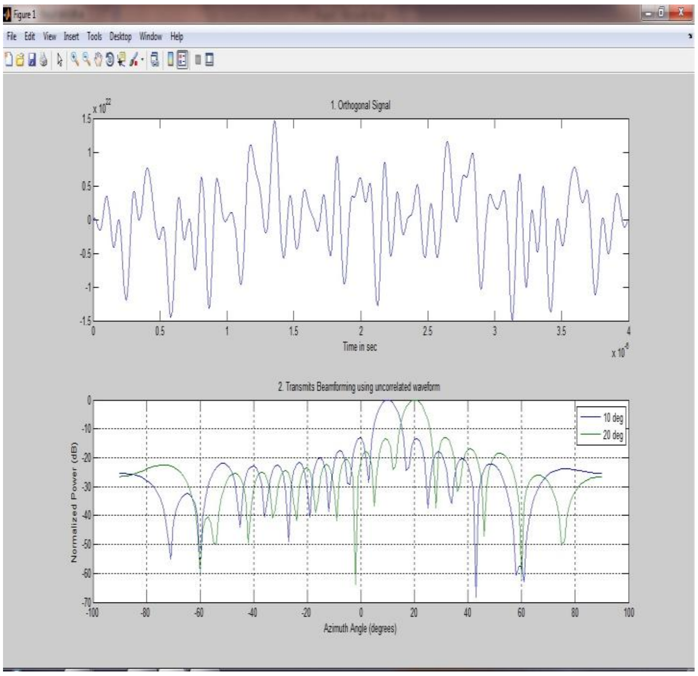

Figure 3: Transmits beamforming using uncorrelated waveform N_T=16 azimuth angle 10^0 and 20^0

5. Transmits Beamforming Application

The design of a multi-rank transmits beamformer for MIMO radar depends on the radar mode of operation, power constraints, clutter characteristics, and so on. In this section we consider transmit beamforming for use during search and tracking.

5.1 Tracking A Single Target

Consider first the case where it is desired to track a single target at a known or estimated direction θ_1. This is a typical situation for radar operating in tracking mode. In order to maximize the SNR at the matched-filter output we want to maximize both the gain of the receive array (by pointing the beam at the target) and the gain of the transmit array $P(\theta_1) = a_T(\theta_1)^H Rs\, a_T(\theta_1)$ This will be achieved if $a_T(\theta_1)$ is the eigenvector corresponding to the largest eigenvalue of Rs. Furthermore, the largest eigenvalue will be maximized if Rs is the unit rank matrix $Rs = w^*_1 w^T_1$. It follows, therefore, that $w_1 = a_T(\theta_1)/\|a_T(\theta_1)\|$, in which case $P(\theta_1) = a_T(\theta_1) a_T(\theta_1)^H$. For a transmit array with unit gain omni-directional elements $a_T(\theta_1)a_T(\theta_1)^H$ =

N_T. In other words, the full coherent gain of the transmit array is achieved in this case.

5.2 Tracking A Multiple Target

In Multiple Beamformer where it is desired to track multiple targets at known directions $\theta_1 \ldots\ldots \theta_K$. This can be accomplished by a rank-K beamformer, where each component beamformer is designed as before, using a steering vector pointing at one of the targets. The non-windowed (or rectangular windowed) beamformer for the k^th target is given by

$$W_K = \frac{a_T\ (\theta_K)}{\sqrt{K}|a_T\ (\theta_K)|} \qquad (18)$$

Where the factor of $1/\sqrt{K}$ reflects the fact that transmit power is equally divided among the targets.

5.3 Search Mode

When the radar is operating in search mode the target directions are unknown. In this case the best strategy is to illuminate uniformly the angular sector of interest. This can be accomplished by generating a "fan" of beams jointly covering the sector of interest. In phased-array radar these beams will be scanned. A MIMO radar can transmit on all beams simultaneously using a set of orthogonal waveforms. In other words, we use a multi-rank beamformer, where the rank equals the number of beams needed to cover the sector of interest.

6. CONCLUSION AND FUTURE SCOPE

In this paper we presented an approach to transmit beamforming and receiver design based on the design of uncorrelated waveform and complex MVDR weights rather than the design as done in previous work. Our proposed beamforming techniques having advantages of Spatial (beamformer) and temporal (waveform) parts of the problem eliminated, High SNR of match detector possible, we can obtain multiple independent measurements about the target, a better detection performance can be obtained, a better spatial resolution can be obtained. It is applicable for both in tracking mode and in search mode beamforming.

The Fundamental property of the proposed Beamformers in suppressing power in all directions except for the arrival direction and better cancellation of side lobes. It is applicable for both in tracking mode and in search mode beamforming. Because of the relative simplicity and transparency of the approach described in this project we believe that it is useful as a reference to alternative transmit beamforming methods.

Future Scope

The concept of virtual array is the key for increasing the spatial resolution in MIMO radar. We have obtained the virtual array through the transmission of orthogonal waveforms and match filtering. However, transmitting orthogonal waveforms decreases the processing gain. There may exist some better approach to obtain the virtual array resolution without compromising the processing gain. This topic is also worthy of further investigation.

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BIOGRAPHIES

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