MIMO radar transmit beampattern synthesis via waveform design for target localization

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Abstract

The problem of transmit beampattern synthesis in multiple input multiple output (MIMO) radar for target localization has received much research attention in recent years. Via properly designing the cross correlation matrix of the transmitted signal waveforms, the majority of transmit energy can be focused into the sector(s) of interest where targets are likely to be located.

In this paper, we propose a novel energy focusing approach which can enhance the intensity of signals reflected from the targets and hence the preferable performance of target localization can be attained. Comparing with the existing energy focusing techniques, our new method realizes a desired pattern via designing the waveform cross correlation matrix rather than the transmit weight vector. Moreover, it does not impose additional transmit power constraints or require a prescribed beampattern to be approximated.

Numerical simulations are carried out to show the effectiveness and superiority of the proposed MIMO radar transmit beampattern design technique compared with existing approaches.

Signal Model

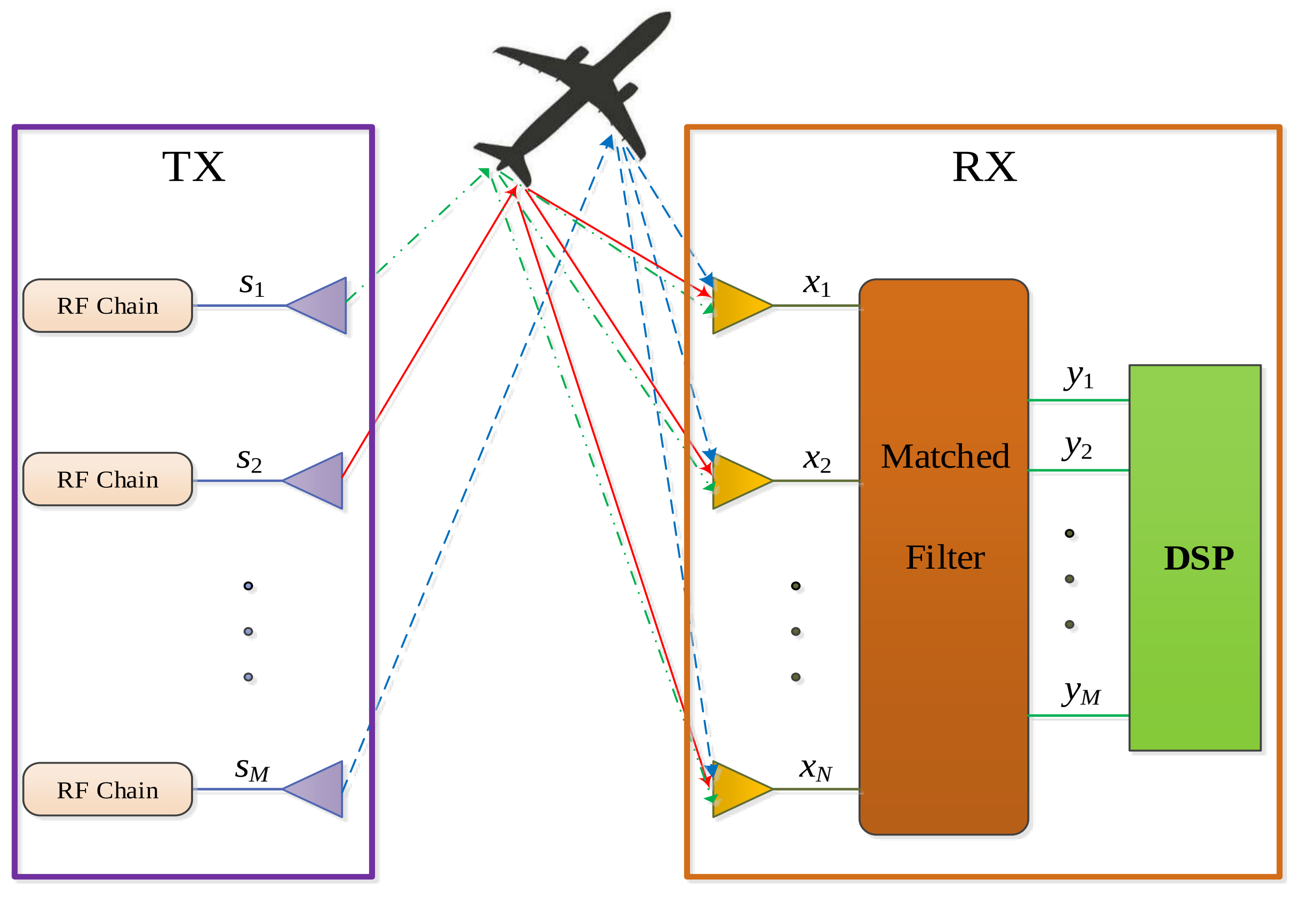

Fig.1 Illustration of the MIMO radar system

Consider a MIMO radar system with M transmit and N receive antennas. The N×1 complex data vector from receive array is

$$\mathbf{x}(t,\tau)=\sum_{k=1}^{K}\beta_k(\tau)\mathbf{a}^T(\theta_k)\mathbf{s}(t)\mathbf{b}(\theta_k)+\mathbf{z}(t,\tau)$$

Stacking the after matched filtering, yields the virtual data vector expressed as

$$\mathbf{y}(\tau)=\sum_{k=1}^{K}\beta_k(\tau)(\mathbf{R}_s^T\mathbf{a}(\theta_k)\otimes\mathbf{b}(\theta_k))+\mathbf{n}(\tau)$$

Proposed Algorithm

In this work, we tackle the target localization problem in MIMO radar via synthesizing the transmit beampattern. By appropriately design the correlation of transmit waveform, most of the transmit energy can be focused into the interested sector(s) which can improve the localization performance certainly. Specifically, the proposed algorithm was divided into the following two steps.

Firstly, through properly manipulating the waveform correlation matrix, the resulting beampattern can maintain a fairly flat power response within the sector of interest and minimize the amount of energy radiated elsewhere.

Secondly, with the designed waveform correlation, the angle parameters of the targets can be determined by pre-whitening the data and exploiting the shift-invariance property.

A. Beampattern Synthesis and DOA Estimation

- Obtain the optimal correlation matrix: $\min_{\mathbf{R}_s}\ \mathrm{trace}(\mathbf{R}_s\mathbf{V})\quad s.t.\ \ |\mathrm{trace}(\mathbf{R}_s\mathbf{Q}(\theta_i))-q_0|\le\delta$
- Pre-whiten the virtual data vector: $\mathbf{y}_\star(\tau)=(\mathbf{R}_{s\star}^*\otimes\mathbf{I}_N)^{-\frac{1}{2}}\mathbf{y}(\tau)$
- Calculate the covariance of the whitened data: $\mathbf{R}_\star=E\{\mathbf{y}_\star(\tau)\mathbf{y}_\star^H(\tau)\}$
- Perform the eigen-decomposition: $\mathbf{R}_\star=\mathbf{E}_s\mathbf{\Lambda}_s\mathbf{E}_s^H+\mathbf{E}_n\mathbf{\Lambda}_n\mathbf{E}_n^H$
- Apply shift-invariance property: $\mathbf{\Psi}=(\mathbf{E}_s^{(1)H}\mathbf{E}_s^{(1)})^{-1}\mathbf{E}_s^{(1)H}\mathbf{E}_s^{(2)}$
- Estimate the direction-of-arrival: $\theta_k=\arcsin(\pi^{-1}\arg(\zeta_k))$

where ζ_k denotes the k-th eigenvalue of $\mathbf{\Psi}$

Simulation Results

Example 1: Transmit beampattern exhibition

- Both the transmit and receive array are ULA with half-wavelength inter-element spacing, M=10 and N=10.
- The sector of interest is set as $\theta_i\in[-30^\circ,30^\circ]$, and two targets located at -8 and 8 degree.

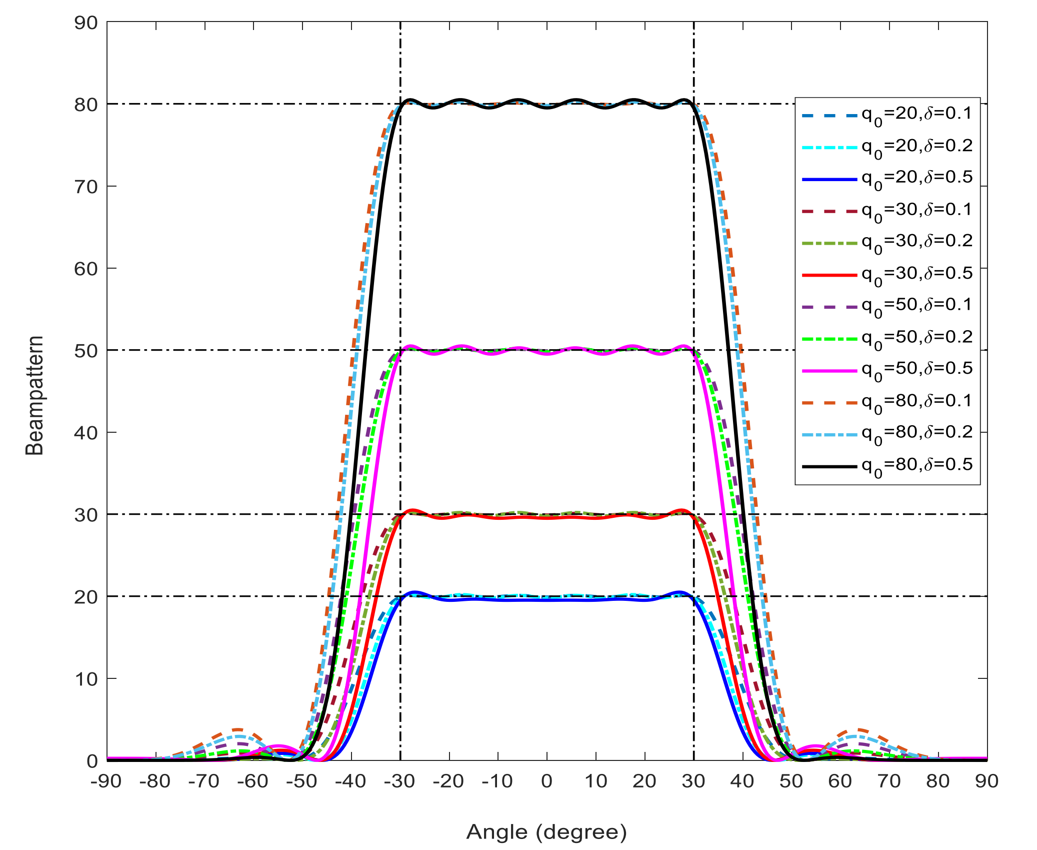

Figure 2. Illustration of the synthesized transmit beampatterns

Simulation Results

Example 2: Root Mean Square Error (RMSE) Comparison

- The total transmit energy is E=5, and the RMSE is computed through 500 independent runs.

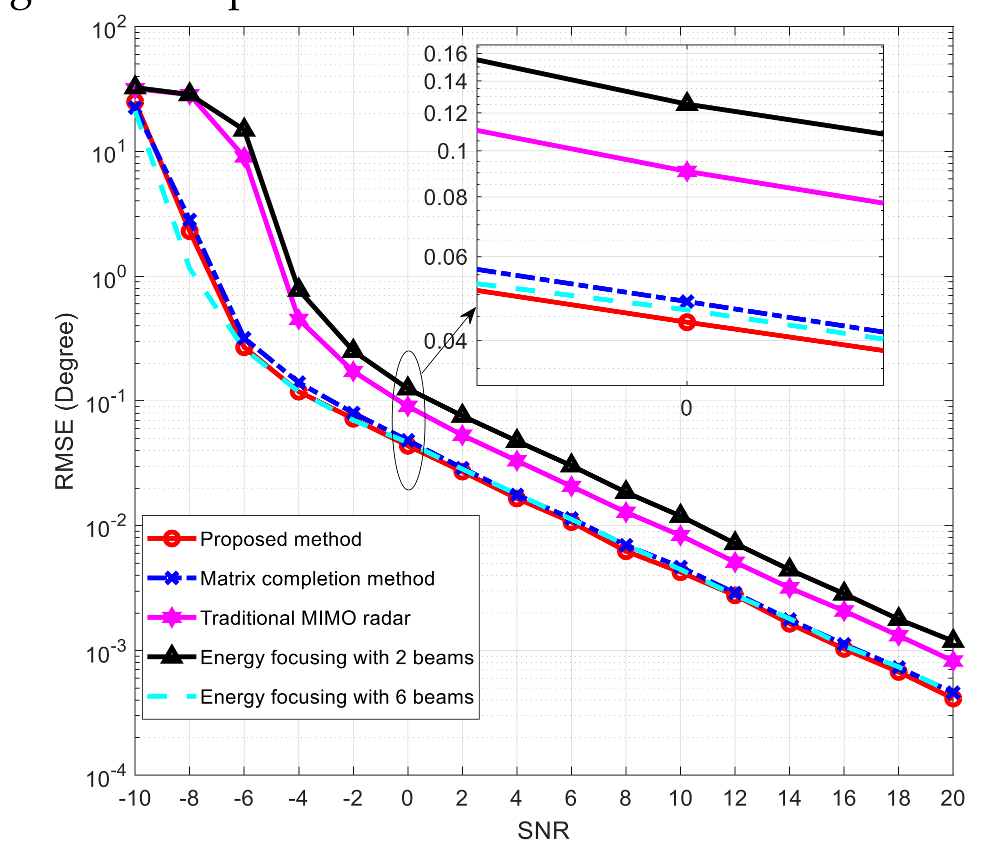

Figure 3. RMSE of DOA estimation versus SNR

Simulation Results

Example 3: Resolution Probability Comparison

- The total transmit energy is E=5.
- The performance of probability resolution is computed through 500 independence experiments.
- The covariance matrix of all examples is obtained by 1000 snapshots.
- If the bias of each DOA estimation is less than 0.25 degree, the source are considered as resolved.

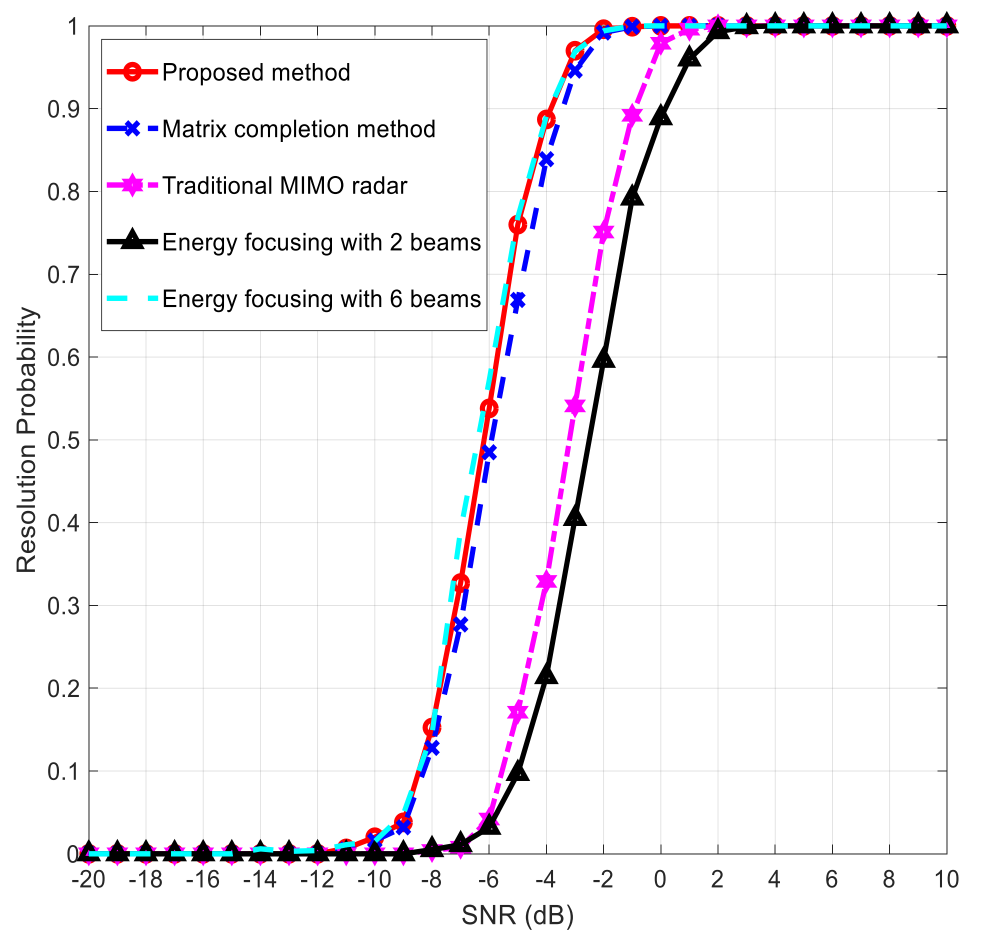

Figure 4. Resolution probability of success versus SNR

Main References

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