MIMO Waveform Design for Minimizing Multipath from Ground and Ceiling Reflections

Aashish Sharma and Shobha Sundar Ram
Dept. of Electronics and Communication
Indraprastha Institute of Information Technology Delhi
shobha@iiitd.ac.in

***Abstract*— Two-dimensional multiple input multiple output (MIMO) radar waveforms are designed for minimizing interference due to multipath from ground and ceiling scattered returns from an indoor point target. The waveforms are optimized with constraints of constant power and/or good pulse compression features. The effect of near and far-field considerations on the performance of the algorithm are studied.**

I. INTRODUCTION

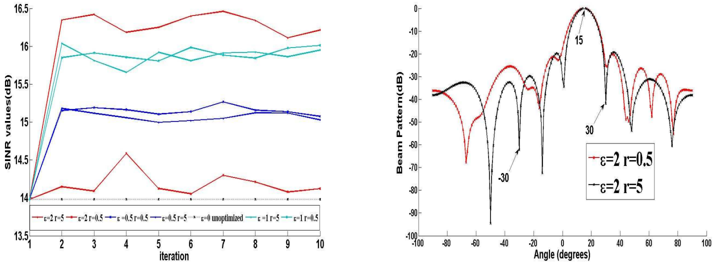
MIMO radars, unlike conventional phased array radars, transmit multiple orthogonal waveforms that can be optimized for realizing superior angular resolution and high clutter rejection [1]. They are broadly of two types - first, where the transmitting and receiving antennas are spatially distributed [2]; second, where the antennas are collocated [3]. In [4], the authors proposed an algorithm for improving the signal to interference and noise ratio (SINR) for a point target in far-field conditions by jointly optimizing the transmitting waveforms and receiver weights of a spatially collocated uniform linear array receiver. Their algorithm minimized signal dependent interferences when the angular positions of both the target and the interference sources are known. In this work, we adapt their algorithm for planar array configurations for minimizing the interference introduced by ground and ceiling reflections for a point target. The capability of removing these multipath components is important while tracking ground based targets such as humans in indoor conditions. The optimization algorithm is implemented with a constant power constraint while retaining good pulse compression characteristics. The second constraint is implemented through a similarity constraint between the phase of the transmitted waveform and the phase of a linear frequency modulated (LFM) waveform. The performance of the algorithm in near and far field conditions is studied.

II. EXPERIMENTAL ANALYSIS

We demonstrate the algorithm on MIMO radars with one dimensional array configurations and then extend it to planar array configurations. First, we consider a uniform linear array consisting of 4 transmitters and 8 receivers along the Z axis (with the ground at $z = 0m$) before a point target that is located at $x = r, z = 2.1m$. The center element of the array is $x = 0m, z = 1m$. We assume that all the transmitted waveforms are narrowband signals at 2.4GHz. The elements are spaced half wavelength apart. The ceiling is at $z = 3m$. Both the ground and ceiling are assumed to be perfectly planar and of a relative permittivity of 7. The propagation through the channel is modeled using ray theory. The transmitting waveforms and the receiver weights are optimized for improved SINR (ρ) for a waveform with 16 time samples in each period, as shown in (1).

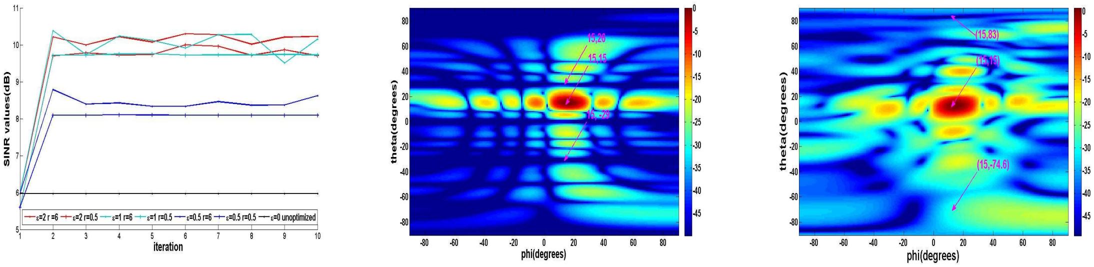
$$\max_{s,\omega} \rho\left(s,\omega\right) = \frac{SNR\left|\omega^{\dagger}A(\theta_0)s\right|^2}{\omega^{\dagger}\Sigma_I(s)\omega + \omega^{\dagger}\omega} \tag{1}$$

Here s is the vector of transmitted waveforms, ω is the vector of receiver weights, $A(\theta_0)$ is the two-way propagation matrix between the radar and the target and $SNR = 20dB$ is the signal to noise ratio at the receiver. Σ_I is the total energy contained in the multipath components from the ground and ceiling. $\dagger$ denotes the transpose conjugate of a vector. The optimization is carried out with the following constraints- One, each transmitted waveform is maintained at unit strength; Two, the phase of the waveform is constrained from deviating significantly from that of an LFM waveform. The similarity constraint is specified by $0 < \epsilon < 2$ where $\epsilon = 0$ if the waveform is identical to the LFM and $\epsilon = 2$ when the waveform has no similarity to the LFM. Detailed exposition of the optimization algorithm is presented in [4]. Fig.1(a) shows the SINR for each iteration of the optimization algorithm for two cases. First, when the target is at $r = 0.5m$ (near-field) from the origin and second, when the target is at $r = 5m$ (far-field) from the origin. In both the cases, the optimization is carried out for three values of the similarity constraint: $\epsilon = 0.5, 1, 2$. As the number of iterations increases, the SINR improves and stabilizes for the far-field case. The performance of the algorithm improves when the similarity constraint is relaxed (for higher values of ϵ). There is a weak convergence for the near-field case, especially when $\epsilon = 2$. However, the SINR values still remain high for ($\epsilon = 0.5$ & 1) since the interference sources fall at end fire positions (-74° and 76°) where the beam pattern has low values as seen in Fig.3(c). Fig.1(b) shows the received beam pattern for both the cases when $\epsilon = 2$. In the far-field case, we note that the peak of the pattern is at 15° which corresponds to the position of the target while the positions of the interference, at 30° and -30°, have nulls. These nulls correspond to the first reflected components from the ground and ceiling and not the higher order components (which can be removed by range gating). Next, we consider a MIMO radar with 2×4 transmitters



(a) (b)

Fig. 1. (a) 1D MIMO Radar waveform optimization for detecting a target, at near-field ($0.5m$) and far-field ($5m$), for maximum SINR with different similarity constraints ($\epsilon = 0.5, 1, 2$) with respect to a linear frequency modulated waveform and the (b) resultant beam patterns at the receivers.



(a) (b) (c)

Fig. 3. (a) 2D MIMO Radar waveform optimization for detecting a target, at near-field ($0.5m$) and far-field ($6m$), for maximum SINR with different similarity coefficients ($\epsilon = 0.5, 1, 2$) with respect to a linear frequency modulated waveform and the resultant beam patterns at the receivers when target is in the (b) far-field and in the (c) near-field.

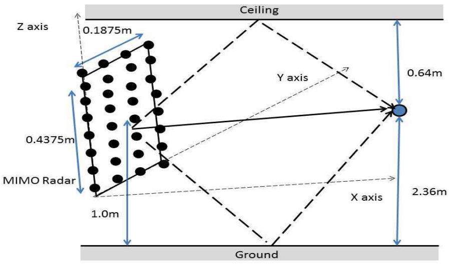


Fig. 2. MIMO radar with planar configuration with multipath from ground and ceiling reflections

and 4×8 receivers arranged in a planar configuration in the YZ plane, as shown in Fig.2. The transmitters are uniformly spaced one wavelength apart while the receivers are spaced half wavelength apart where the wavelength is $12.5cm$. Again the ground and ceiling are located at $z = 0, z = 3m$ respectively. The center of the array is at $x = 0, z = 1m$ while the target is at $x = r, z = 2.36m$. The scattered returns from the point target consist of direct, ground reflected and ceiling reflected rays, and higher order scattering. Fig.3(a) shows the SINR achieved by joint optimization of the transmitting waveforms and the receiver weights. The results are consistent with the trends observed for the 1D MIMO. The performance of the algorithm improves when the similarity constraint is relaxed. The algorithm is successful in creating nulls at the dominant interference locations ($\theta = -29°, \phi = 15°$) and ($\theta = 26°, \phi = 15°$) when the target is in the far-field with respect to the radar as seen in the beam pattern in Fig.3(b). Here, θ and ϕ are the elevation and azimuth positions of the point scatterer with respect to the radar. The performance of the algorithm deteriorates in the near-field condition as seen in Fig.3(c) when the interference sources are located at angular positions ($\theta = -74.6°, \phi = 15°$) and ($\theta = 83°, \phi = 15°$).

III. CONCLUSION

Multipath interference from the ground and ceiling are minimized for improving the SINR of planar MIMO radar configurations while retaining good pulse compression features.

ACKNOWLEDGEMENT

This work is supported by the DST Inspire Fellowship Award by the Government of India.

REFERENCES

[1] J. Li and P. Stoica, *MIMO radar signal processing*. Wiley Online Library, 2009.

[2] A. M. Haimovich, R. S. Blum, and L. J. Cimini, “Mimo radar with widely separated antennas,” *Signal Processing Magazine, IEEE*, vol. 25, no. 1, pp. 116–129, 2008.

[3] J. Li and P. Stoica, “Mimo radar with colocated antennas,” *Signal Processing Magazine, IEEE*, vol. 24, no. 5, pp. 106–114, 2007.

[4] G. Cui, H. Li, and M. Rangaswamy, “Mimo radar waveform design with constant modulus and similarity constraints,” 2014.