Optimal Design of Sparse MIMO Arrays for Compressive Sensing based UWB Imaging in Layered Media

Qiang An* (1, 2) and Ahmad Hoorfar(2)
(1) Department of Biomedical Engineering, Fourth Military Medical University, Xi'an 710032, China
(2) Antenna Research Laboratory, Center for Advanced Communications, Villanova University, Villanova, PA 19085, USA
qan01@villanova.edu, ahoorfar@villanova.edu

Multiple-input multiple-output (MIMO) radar systems have been often adopted in imaging of targets in layered media, for example in through-the-wall-radar-imaging (TWRI) and ground penetrating radar (GPR) applications, since they can provide considerable flexibility on array configuration while maintaining a rather low system complexity. Conventional focusing approaches like back-projection (BP), modified range migration (MGF), and far-field Green's-function based focusing technique (GF) exhibits inadequacy when synthesizing the spatially highly under-sampled data. Fortunately, compressive sensing (CS) theory can be successfully applied here. Based on CS theory, an accurate reconstruction of a sparse scene, which often holds true in TWRI, can be realized even if the scenes are sampled at far lower than Nyquist's rate by solving an optimization problem. Compressive measurement which can reduce the mutual coherence of the sensing matrix is the key for reliable reconstruction. However, for a real MIMO radar, it is rather hard to construct a typically utilized measurement matrix like Gaussian random matrix. It has been shown that the randomness of a sparse random array is equivalent to the random measurement in the CS [L. Carin, IEEE Antennas and Propagation Magazine, 2009; L. Carin, D. Liu, and B. Guo, IEEE Antennas and Propagation Magazine, 2011].

Based on the above works, we have studied in this paper the construct of optimal random MIMO array for nearfield ultra-wideband (UWB) TWRI and GPR using the randomness of the array elements to achieve compressive measurement. The mutual coherence of the equivalent sensing matrix obtained using the sparse random MIMO array is minimized via simulated annealing. In general, Compressive Sensing (CS) has been proved to be an effective way to detect and image the unknown objects in TWRI and GPR sparse scenes using the spatially under-sampled data acquired by MIMO arrays, in which the optimal sensing matrix selection is of vital importance for the reliable reconstruction [W. Zhang and A. Hoorfar, IEEE AWPL, 2015]. Also, it is well acknowledged that the mutual coherence actually controls the sidelobe level in CS reconstruction. The lower the value of mutual coherence is, the better is the image quality. In MIMO TWRI and subsurface imaging scenarios, the sensing matrix selection problem degenerates to the optimal measurement matrix design problem. In this work, to optimize a sparse MIMO array for CS based TWRI, we incorporate the randomness of array elements into the construction of sensing matrix and consider the well-known mutual coherence as an optimization criteria. To account for the ghost effects introduced by the multiple reflections within the wall or the subsurface layers in GPR, the transmission coefficients are utilized in the proposed technique. Simulated annealing is then applied to reduce the coherence of the equivalent sensing matrix.

Numerical examples, showing the effectiveness of the proposed approach, and the extension of this work to account for extended target or targets with block-sparse properties, will be presented.