Optimal Design of Sparse MIMO Arrays for Ultra-wideband TWRI

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

In real life through-the-wall-radar-imaging (TWRI) applications, using multiple-input-multiple-output (MIMO) arrays, various array topologies such as Mill-Cross, Y-shape, Curvilinear arrays have been proposed by many researchers in order to achieve attributes such as ease of portability and light weight, while maintaining a good image reconstruction quality. Most of these designs were derived based on the virtual array theory or by exerting some constraints on the far-field radiation pattern like mainlobe beamwidth and/or sidelobe levels. Unfortunately, all these approaches will inevitably result in elevated sidelobe levels in the final image, which is mainly caused by the sparseness of the array under the limit of restricted number of antenna elements. The array topology proposed in [K. Tan, et al., IEEE Transactions on Antennas and Propagation vol. 65, no. 2, 2017], uses a maximum projection theory to handle this problem. MIMO channel weighting via optimization was reported to yield a good sidelobe suppressing ability [Y. Liu, X. Xu, and G. Xu, IEEE Transactions on Aerospace and Electronic Systems, 2017]. Array topology design based on minimizing reconstruction error is also shown to be effective [M. B. Kocamis, and F. S. Oktem, Signal Processing Conference (EUSIPCO), 2017]. However, above array configurations are suggested to be sub-optimal for short-distance ultra-wideband (UWB) TWRI, in which the virtual phase center hypothesis may not hold. Moreover, none of the aforementioned methods consider the wave propagation effect introduced by the wall when designing the optimal array topology. Thereby, it is desirable to develop new schemes to account for these two aspects of the problem.

In this presentation, a two-stage sparse MIMO array topology design method, aimed for short-distance UWB TWRI under a Bayesian estimation framework, will be detailed. The method first start from a full array (uniform or random) to minimize the sum of squared errors (SSE) utilizing the clustered sequential backward selection (CSBS) algorithm to get a preliminary array topology for a desired number of antennas. Then, employing the concept of antenna array information capacity developed originally in the communication society as a figure of merit of antenna array rearrangement, the second step maximizes the information capacity of objects behind the wall from a given physical aperture. Simultaneous perturbation and statistical algorithm (SPSA) are used here to efficiently solve the optimization problem in this stage. In addition, by using the Green's function based focusing and incorporating the transmission coefficients of the wall layers into the optimization process, the short-distance concern and the wall effect are both carefully accounted for in the design. Notably, the approach proposes a concept of environmentally dependent array topology design by taking into account the dependence of array topology and investigating regions of interest, including walls. As a result, improved imaging quality can be obtained with the proposed sensor array. Numerical examples with comparison to other state-of-the-art topologies for TWRI scenarios will be presented to demonstrate the enhanced focusing ability of the final proposed topology. In addition, optimal array topology variations with regard to different types of walls (brick wall, concrete wall, reinforced wall, hollow concrete wall, etc.) will also be discussed.