General MIMO Framework for Multipath Exploitation in Through-the-Wall Radar Imaging

Michael Leigsnering[1], Fauzia Ahmad[2], Moeness G. Amin[2], and Abdelhak M. Zoubir[1]

[1] Signal Processing Group, Institute of Telecommunications, Technische Universität Darmstadt, 64283 Darmstadt, Germany
[2]Radar Imaging Laboratory, Center for Advanced Communications, Villanova University, Villanova, PA 19085 USA

Detection and localization of stationary and moving targets within a building or an enclosed structure are highly desirable in through-the-wall radar imaging (TWRI) and urban sensing applications. These objectives are primarily challenged by two factors. First, multipath propagation of the electromagnetic waves gives rise to ghost targets [1]. Second, the need for highly resolved images results in acquisition, storage, and processing of huge amounts of data [2]. To this end, we propose a general MIMO framework for exploiting multipath propagation employing compressive sensing (CS).

Many practical TWRI systems use several switched transmit antennas and a receive array, which is a time-multiplexed MIMO radar configuration [3]. Specular reflections at interior walls give rise to virtual transmitters and receivers that extend the aperture of the real array. However, the virtual transmitters, by definition, transmit exactly the same signal as the physical transmitter. Likewise, the signals measured by the physical receivers contain the contributions of the virtual receivers as well. Assuming knowledge of the building layout, we model the system in a general MIMO framework, incorporating all additional virtual transmitters and receivers. This model can be seen as a generalization of a standard MIMO setup. It incorporates not only MIMO operation corresponding to direct path propagation, but also multipath propagation in a SIMO setup. All targets are modeled as either stationary or moving with a constant velocity. Hence, we aim at acquiring both the locations and velocities of all targets.

By employing the aforementioned model and assuming that only a few targets reside inside the room, CS can be employed to invert the model and reconstruct the target information [4]. More specifically, we propose a reconstruction approach based on group sparsity. Assuming co-located MIMO, coherence is preserved for the direct response of the targets involving the physical transmit/receive array. Likewise, this observation holds for any particular pair of physical or virtual transmit/receive arrays. Hence, this data is processed coherently across a certain number of pulses. However, the phase of the reflected wave is likely to be unknown across different physical or virtual transmitter/receiver pairs, as the targets are seen from different aspect angles or bistatic angles. Hence, the proposed CS reconstruction scheme employs coherent processing within pairs of arrays and non-coherent processing across different pairs of arrays. For each pair of arrays, a separate image is reconstructed. However, all such images are constrained to have (almost) the same support. This is achieved through a mixed ℓ_1/ℓ_2-norm reconstruction.

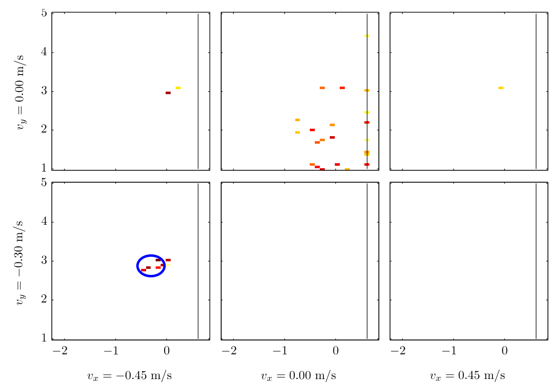

Fig. 1. Example experimental result of a walking human.

The proposed approach is validated using experimental data acquired at the Radar Imaging Lab, Villanova University. The data is recorded using a pulsed radar with 3 GHz bandwidth, one transmitter, 8 element receive array, and a system refresh rate of 100 Hz. The scene consisted of a human walking diagonally across a room towards the radar. There was no front wall, and the back wall was covered with RF absorbing material. A multipath response from the reinforced concrete side wall was observed. The corresponding reconstruction results are shown in Fig. 1 using 20% of the Nyquist samples. For each velocity pair (v_x, v_y), an image of the scene is reconstructed; only the non-zero images are displayed as subplots in Fig. 1. Faithful reconstruction of the location and velocity of the human is possible and ghost targets due to multipath propagation are suppressed. However, some clutter remains in the stationary image and neighboring velocity cell.

References

[1] P. Setlur, M. Amin, and F. Ahmad, "Multipath model and exploitation in through-the-wall and urban radar sensing," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 49, no. 10, pp. 4021–4034, 2011.

[2] Y.-S. Yoon and M. Amin, "Compressed sensing technique for high-resolution radar imaging," in *Proceedings of SPIE*, vol. 6968, no. 1, 2008, p. 69681A.

[3] J. Qian, F. Ahmad, and M. G. Amin, "Joint localization of stationary and moving targets behind walls using sparse scene recovery," *Journal of Electronic Imaging*, vol. 22, no. 2, pp. 021 002–021 002, 2013.

[4] M. Leigsnering, F. Ahmad, M. Amin, and A. Zoubir, "Multipath exploitation in through-the-wall radar imaging using sparse reconstruction," *IEEE Trans. on Aerospace and Electronic Systems*, 2012, submitted for pub.