Radar Mapping of Building Structures Applying Sparse Reconstruction

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The ability to map building structures at a certain stand-off distance allows intelligence, reconnaissance, and clearance tasks to be performed in a covert way by driving around a building. This will greatly improve security, response time, and reliability of aforementioned tasks. Therefore, through-the-wall radar systems supporting stand-off mapping of building structures will be an important asset for emergency services and defense organizations. The development of such radar systems is however still in an early stage.

TNO has developed an innovative concept to map building structures with stand-off, through-the-wall radar: SAPPHIRE. The SAPPHIRE processing relies on the specific phase relations of principal scatterers in a 3D measurement grid. The structure of a building can be represented by the combination of these principal scatterers. Four types of principal scatterers can be distinguished, each inducing a different phase behavior in the measured 3D radar data:

- Planar walls give rise to a linear phase change in azimuth and elevation;
- Vertical dihedral corners (wall-wall) induce a quadratic phase change in azimuth and a linear phase change in elevation;
- Horizontal dihedral corners (wall-ceiling) give rise to a linear phase change in azimuth and a quadratic phase change in elevation;
- Trihedral corners (wall-wall-ceiling) induce a quadratic phase change in both azimuth and elevation.

This phase behavior can be used to identify and locate the different scatterers inside a building. The intrinsic sparsity of a building is exploited by using an overcomplete dictionary with sparse reconstruction. If a set of dictionaries $\mathbf{A}_i$, i=1,…,N (i.e. a set of basis functions) is built, each matching the N different types of phase relations induced by different scatterers, then a sparse representation is obtained for each subset of dominant reflectors. An overcomplete dictionary $\mathbf{A}$ can be obtained by combining all the dictionaries $\mathbf{A}_i$, i.e. $\mathbf{A} = [\mathbf{A}_1,\ldots, \mathbf{A}_N]$ and the measured data can be written as

$$\mathbf{y} = \mathbf{A}\mathbf{x}, \qquad (1)$$

where $\mathbf{x} = [\mathbf{x}_1^T,\ldots,\mathbf{x}_N^T]^T$ is a vector of vectors, each one of size P x Q x R, where P, Q, and R are the range, azimuth, and elevation direction of the 3D data cube. Each $\mathbf{x}_i$ is a sparse vector containing the complex amplitude of each dominant reflector of type i present in the scene at its respective 3D location. For the sparse reconstruction the SPGL1 solver has been used [www.cs.ubc.ca/labs/scl/spgl1/].

A measurement campaign has been carried out during which 3D radar data were obtained from a building. For this campaign the SAPPHIRE system was placed on a sensor rail and driven along the building (see inset in Fig. 1).

The results of a single measurement run are presented in Fig. 1. The background image (colored image) shows the result from applying synthetic aperture radar processing. The black lines (─) indicate walls and the hooks (┐ or ┘) indicate dihedral corners.

The results show that the method is robust with respect to radar propagation through walls. Principal scatterers are found even after propagation through two or three walls. The scatterer locations match with the ground truth. However, the method is sensitive to model inaccuracies.

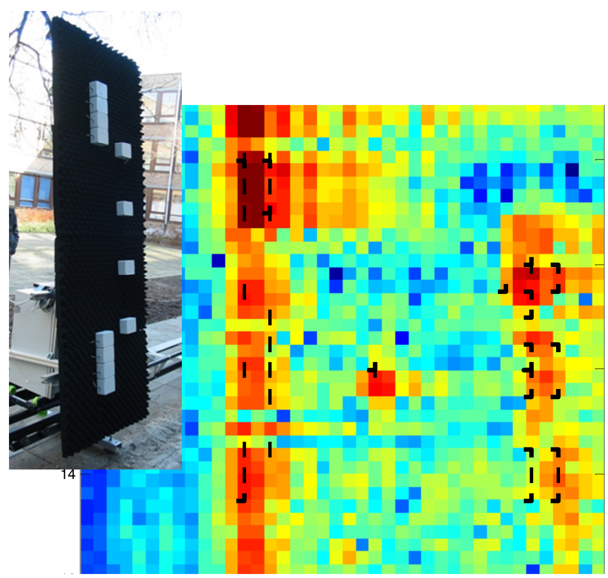

Figure 1. Results of the sparse reconstruction.

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