Sparse Multilayered Subsurface Imaging in MIMO Radar Using Total Variation Minimization

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Over the past decade, the imaging of targets embedded in multilayered dielectric media has become of paramount importance in a diverse set of problems including those in microwave remote sensing, nondestructive testing, ground penetrating radar (GPR), and through-the-wall imaging (TWRI). For high resolution imaging in these applications, usually a long aperture is synthesized using an ultra-wideband transmitted signal, which makes the approach impractical and/or costly in many realistic situations. Therefore, it is important to devise techniques that reduce the collected data volume in order to accelerate radar data acquisition and processing times such that prompt actionable intelligence would be possible. To meet these objectives many research groups in recent years have applied Compressive Sensing (CS) to radar imaging in free space, GPR, and TWRI to reconstruct a sparse radar image from far fewer non-adaptive measurements. The standard CS techniques, however, are mainly based on L1-norm minimization which is primarily effective in detecting the presence of targets as it cannot accurately reconstruct the target shape and/or differentiate closely-spaced targets from an extended target.

In this presentation, we give an overview of some of our recent works on sparse image reconstruction for step-frequency multi-input multi-output (MIMO) radar through multilayered background media using the concept of Total Variation Minimization (TVM). The TVM technique, which in its basic form was originally proposed for image processing more than two decades ago [*L. Rudin, S. Osher, and E. Fatemi, Phys. D, Nonlinear Phenomena, Nov. 1992*], has recently been successfully applied in a number of the CS-based inverse profiling and radar imaging problems. In general, it minimizes the gradient of the image resulting in better edge preservation and shape reconstruction than the standard L1-norm minimization. In our proposed approach, the MIMO implementation overcomes the main drawback of monostatic radar, which is the long data acquisition time, whereas TVM significantly reduces the hardware complexity of MIMO radar system, which typically requires a large number of antenna elements. To speed up the processing, the Green's functions of multilayered media are efficiently evaluated using the saddle-point method and fully incorporated in the imaging algorithm. The resulting closed-form expressions for the Green's functions allow the application of the proposed algorithm in a unified manner to both multilayered subsurface imaging in GPR as well as to multilayered-wall target imaging in TWRI.

Numerical examples for various GPR and TWRI scenarios will be presented to demonstrate that the number of transmitting and receiving antenna elements as well as the number of frequency bins in the MIMO radar system can be significantly reduced using the proposed approach without degradation of the image quality and with the targets geolocations and shapes accurately reconstructed. In addition, we will discuss an extension of the method to the forward-looking GPR scenarios through an analytical modification of the Green's function for grazing incidence cases.