Iterative Thresholding Matched Filters for Sparse Radar Targets

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Many radar applications for sensing space plasma necessitate the use of coded pulses for good range accuracy and sensitivity under peak power constraints. When codes are used, the matched filter is often applied during processing to maximize the signal-to-noise ratio (SNR) for detection and analysis. In the case of moving targets with unknown velocity (e.g. meteor head echoes) or the general case when the entire frequency spectrum of a signal is of interest (e.g. incoherent scatter or multiple scatterers with different Doppler shifts), a bank of matched filters is used, each adapted to a different frequency. One problem with most codes and their corresponding matched filter is processing sidelobes: spurious signal appearing at non-target locations in the range-frequency matched filtered result. One approach for minimizing or eliminating sidelobes is to use a non-matched filter. Often this is an inverse filter that results in no range sidelobes at the cost of reduced SNR. Another approach is to employ codes that minimize sidelobes (Barker, LFM chirp, or minimum peak sidelobe codes) or practically eliminate them (perfect codes) when the matched filter is used. Whether mismatched or matched filters are used, both approaches are typically formulated to minimize range sidelobes but ignore frequency sidelobes. A new approach is needed to decode complex scatterers which require discrimination in both range and frequency.

Since in principle the form of the sidelobes is known by knowing the code, inversion is another option for removing sidelobes. The difficulty is that the inverse problem is under-determined, so an infinite number of solutions can be found that fit the radar measurements. Fortunately, in radar applications we typically have knowledge that the target has a sparse representation in range and frequency, and we can use this a-priori knowledge to find a unique solution. In this talk, we describe the concept of Iterative Thresholding Matched Filters for performing inversion on the radar signal to remove range-frequency sidelobes. This technique is applicable using a wide range of codes provided that the target signal is sparse in the range-frequency domain.

First, we introduce the inversion concept by formulating a radar model that is the adjoint of the range-frequency matched filter. We then present the results of an alternative model derivation that shows the conditions under which sparsity is preserved when going from a continuous to discrete target representation; of particular interest is the important case of arbitrarily-located point targets. The model is under-determined by definition, but the sparsity assumption allows us to turn to the theory of compressed sensing in order to get a unique solution. The inversion process requires solving a convex optimization problem, and we discuss different first-order algorithms for solving large instances of this problem. Since the solution procedure for all of these involves an iterative procedure of thresholding and matched filtering, we call these techniques Iterative Thresholding Matched Filters. We conclude with examples of this technique applied to meteor head and trail echoes.