Time-reversal Strategies for Extended Target Imaging and Focusing, and Clutter Nulling

E. A. Marengo
Northeastern University, USA

Time-reversal (TR) imaging has been shown (see [1], and the references therein) to be a useful strategy for super-resolved imaging of M point targets from the multistatic response matrix (MRM) K measured by an array of $N > M$ co-located transmitters and receivers. This method works even if there is significant multiple scattering among the targets. For the particular non-multiply scattering case the MRM $K = \sum_{m=1}^{M} \tau_m g(\mathbf{x}_m) g^{*\dagger}(\mathbf{x}_m)$ where † denotes the adjoint, the τ_m's are the target scattering strengths, the $g(\mathbf{x}_m)$'s are linearly independent N-long Green function vectors or "propagators" corresponding to the target locations $\mathbf{x}_m$, and the $g^*(\mathbf{x}_m)$'s are the associated "backpropagators". If (u_i, v_i, λ_i) is the singular system of K, where $K_{u_i} = \lambda_i v_i$, then if $\lambda_i = 0$ the inner product $u_i^\dagger g^*(\mathbf{x}_m) = 0$ for all $m = 1, 2, \ldots, M$ so that in the absence of additive noise the TR MUSIC pseudospectrum $P(\mathbf{x}_m) = (\sum_{\lambda_i=0} |u_i^\dagger g^*(\mathbf{x}_m)|^2)^{-1}$ peaks at the correct target locations while in the presence of noise it yields an image of the targets. In this theory there is a single propagator $g(\mathbf{x}_m)$ and its companion backpropagator $g^*(\mathbf{x}_m)$ per point target. But, as is well known (see [2–4]), for extended targets whose size is not small relative to the smallest probing wavelength one must associate a set of propagators and backpropagators per each target (they depend on both the target's shape and position). The question then arises how to optimally generalize TR imaging when the targets are extended. This generalization is desirable for realistic applications in ground-penetrating radar, SAR imaging, and inverse scattering of large objects. A treatment based on the Born approximation is given in ([5]) which focuses on extended targets that have a uniform scattering potential. The present work considers the more general exact scattering regime and non-uniform scatterers, and also provides a new framework to treat space-time information in TR. The general theory is based on the fact that for a broad class of problems the MRM K essentially takes the more general form $K \simeq \sum_{m=1}^{M} \sum_{q=1}^{\alpha_m(\mathbf{x}_m)} \tau_{m,q} \pi_m^{(q)}(\mathbf{x}_m) [\Pi_m^{(q)}]^\dagger(\mathbf{x}_m)$ where $\alpha_m(\mathbf{x}_m)$ is a finite number of degrees of freedom corresponding to the relevant signal-to-noise ratio (SNR) and where the $\pi_m^{(q)}(\mathbf{x}_m)$'s and $\Pi_m^{(q)}(\mathbf{x}_m)$'s form respective sets of propagators and backpropagators *per target*. The generalized form of the pseudospectrum valid for extended targets can then be shown to be $P(\mathbf{x}_m) = (\sum_{\lambda_i=0} \sum_{q=1}^{\alpha_m(\mathbf{x}_m)} |u_i^\dagger \Pi_m^{(q)}(\mathbf{x}_m)|^2)^{-1}$ which theoretically peaks at the correct target locations. This method and yet more generalized variants of it are validated in this talk with the aid of computer simulations.

The proposed approach can be implemented for cases of increasing complexity ranging from known targets, to targets of partially known support, to completely unknown targets whose support one attempts to deduce from the data. An application emphasized in this talk is imaging of an extended target in the presence of certains kinds of clutter which do not limit the information space versus data space dimensionality restrictions of all TR approaches. This includes ways of suppressing the clutter by reducing the data subspaces that are associated mainly to clutter (interference) which enhances signal-to-interference ratio. Another application, within the medical context, is the minimally invasive focusing of wave energy in a target surrounded by clutter (e.g., surrounding organs).

REFERENCES

1. Gruber, et al., *J. Acoust. Soc. Am.*, Vol. 115, 3042–3047, 2004.
2. Chambers, D. H. and J. G. Berryman, *IEEE Trans. Antenn. Propagat.*, Vol. 52, 1729–1738, 2004.
3. Chambers, D. H. and A. K. Gautesen, *J. Acoust. Soc. Am.*, Vol. 109, 2616–2624, 2001.
4. Chambers, D. H., *J. Acoust. Soc. Am.*, Vol. 112, 411–419, 2002.
5. Zhao, H., *SIAM J. Appl. Math.*, Vol. 64, 725–745, 2004.