URSI-B EMTS 2025, Bologna, 23–27 June

Enhanced resolution imaging in strongly scattering media

Alexander Christie(1), Matan Leibovich(2), Miguel Moscoso(3), Alexei Novikov(4), George Papanicolaou(1), Chrysoula Tsogka*(5)
(1) Stanford University, Stanford, CA 94305, USA
(2) Courant Institute of Mathematical Sciences, New York University, New York, NY 10012, USA
(3) Universidad Carlos III de Madrid, Leganes, Madrid 28911, Spain
(4) The Pennsylvania State University, University Park, PA 16802, USA
(5) University of California, Merced, CA 95343, USA; e-mail:ctsogka@ucmerced.edu

Imaging in complex media is challenging as multiple scattering leads to loss of directional information and coherence. Unless the complex propagation medium is known, or can be accurately estimated, coherent imaging typically fails [1]. We propose an approach that allows for imaging in such strongly scattering media by accurately estimating the sensing matrix in the complex medium using both conventional optimization algorithms and neural networks by exploiting large and diverse data sets [2]. An essential assumption is that a diverse data set is available and each vector of this data set corresponds to a sparse scene. No knowledge about the sparse scene is necessary.

The proposed approach allows for high resolution images in strongly scattering media. Enhanced resolution, better than in homogeneous media is achievable due to an effective array aperture, larger than the physical array one arising due to the multiple scattering [3]. The stability of the imaging algorithm depends on the size of the physical array and on the bandwidth.

Motivated by [4], which deals with weakly scattering media, we propose two different approaches to estimate the sensing matrix from large and diverse data sets, one that relies on conventional optimization methods and one that uses neural networks. The first approach involves three steps: (i) Get a preliminary, low quality estimate of the columns of the sensing matrix. (ii) Apply dictionary learning, *i.e.* a non-convex optimization which is initialized by the preliminary estimate and leads to an improved estimate for the columns of the sensing matrix. (iii) Use a neighborhood based (non-metric) multidimensional scaling algorithm to order the estimated columns of the sensing matrix. Although in most applications of dictionary learning the order of the columns is not an issue, it is essential in imaging.

In the neural network based approach, we use an encoder-decoder architecture trained on the diverse data to get accurate estimates of the unordered sensing matrix from multiple realizations of the trained network. This step is then followed by a clustering step using DBSCAN. The last step is the ordering step which is the same as for the conventional optimization approach.

The main advantage of the neural network approach is that no initialization is needed. Accuracy is gained by generating multiple versions of the columns of the sensing matrix, followed by clustering. No elaborate fine-tuning of the hyper-parameters of the neural network is needed. The main advantage of the conventional non-convex optimization approach is that we have very good control of accuracy, but a good initialization is necessary.

References

[1] L. Borcea, J. Garnier, G. Papanicolaou and C. Tsogka, Enhanced statistical stability in coherent interferometric imaging, Inverse Problems, **27**, p. 085003 (2011).

[2] Alexander Christie, Matan Leibovich, Miguel Moscoso, Alexei Novikov, George Papanicolaou, and Chrysoula Tsogka, Super-resolution in disordered media using neural networks, arXiV 2410.21556, 2024.

[3] P.-D. Letourneau, Y. Wu, G. Papanicolaou, J. Garnier, and E. Darve, A numerical study of super-resolution through fast 3D wideband algorithm for scattering in highly-heterogeneous media, Wave Motion, 70, 113-134 (2017).

[4] Miguel Moscoso, Alexei Novikov, George Papanicolaou, and Chrysoula Tsogka, Correlation-informed ordered dictionary learning for imaging in complex media Proc. Nat. Acad. Sci, vol. 121(11), e2314697121, 2024.