Model-based Tensor Decompositions for Bio- and Geophysical Parameter Retrieval

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The increasing availability of multidimensional SAR data motivates the development of new techniques for analysis, decomposition, and joint information extraction. In this work, we explore the integration of physical polarimetric models into tensor decompositions to estimate geophysical parameters like soil moisture.

In vegetated areas, SAR backscatter signal contains both the information about the ground and the vegetation due to the penetration into the media. Therefore, to accurately estimate the soil parameters, the methods should take into account the vegetation backscatter. Polarimetric physical models approximate the signal with a sum of different components that describe both the ground and the vegetation contributions [1]. In order to avoid ambiguous model inversion, the total number of model parameters is limited by the number of observables. Current approaches typically use physical models with a small number of parameters. This can result in cases where the model is not able to accurately describe the data or has a small validity range.

Moving towards the inversion of more complex models, we propose to enlarge the observation space by integrating and jointly processing additional data dimensions such as spatial, temporal or polarimetric information. We introduce model-based tensor decompositions that directly operate on data tensors representing them as a sum of model-based tensor components. The larger observation space combined with sharing of certain parameters along the new data dimensions allows to use more complex and accurate models. To illustrate the approach, we present a method to estimate soil moisture from a combination of polarimetric and spatial data, represented as a three-dimensional tensor. Given a small spatial image patch with several independent polarimetric coherency matrices in every pixel, we assume a constant soil moisture across the patch, while letting other parameters like vegetation backscatter intensity vary from pixel to pixel.

The model inversion is formulated as an optimization problem. We use the physical model to reconstruct an approximation tensor from the physical parameters and iteratively minimize the distance between the approximation and the measured data. After convergence, the algorithm provides the physical parameters that fit the data best. Since the model is a differentiable mathematical function, minimization is performed with an optimizer based on gradient descent. The algorithm is implemented in PyTorch taking advantage of automatic differentiation and advanced optimizers.

We evaluate the proposed method on high-resolution airborne F-SAR data obtained by DLR over agricultural areas during the HTERRA 2022 campaign in the province of Foggia, Italy. The decomposition provides a characterization of the dominant scattering mechanism for each resolution cell. In addition, soil moisture estimation at a 12 meter resolution is obtained. The larger observation space and the use of the more accurate model allow the inversion in more regions than compared to a simpler X-Bragg model.

References

[1] I. Hajnsek, T. Jagdhuber, H. Schon, and K. P. Papathanassiou, “Potential of estimating soil moisture under vegetation cover by means of PolSAR,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 47, no. 2, pp. 442–454, 2009.