Self-Regularizing Neural Network for Photothermal and Photoacoustic Depth Profiling

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In the last decades significant progress has been made to solve the inverse problem in photothermal and photoacoustic depth profiling, i.e. the reconstruction of a thermal conductivity, resp. elastic parameter depth profile of an inhomogeneous material from the frequency or time dependence of a photothermal or photoacoustic signal. Though analytical methods have been developed for a limited number of cases, the most successful methods were singular value decomposition or thermal wave backscattering [1], genetic algorithms [2], non-negatively constrained conjugate gradient algorithms [3], and neural networks [4], [5].

In this work we focus on neural network recognition of thermal and elastic depth profiles from resp. photothermal and photoacoustic signals. Neural networks have the great advantage that, once trained, they deliver an immediate profile reconstruction at their input for a given experimental signal. They are very flexible to use and require no simplifications or approximations on the theoretical model describing the relation between material profile and measured signal spectrum. In the usual approach, one independent neural network is trained to determine the material parameter for every depth of interest. Though this kind of approach is simple, straightforward, and gives a good fit of the a posteriori signal (i.e. the signal calculated from the reconstructed profile) to the true signal, the independent determination of the thermal conductivity at different depths does not allow the introduction of a priori information in the functional dependence of the reconstructed profile.

In this paper we present a 'self-regularizing' neural network architecture. In this approach, different neural networks are trained simultaneously to recognize profile parameters which are relevant for the class of materials investigated, or expansion coefficients of the profile in a given set of suitable basic functions. In this way, the resulting profile always fulfills the a priori wanted functional dependence. However, since the signal is often not clearly coupled to these profile parameters, in our combined neural network architecture, the functional dependence is introduced inside of the feedback which is followed during the iterative search for the best set of neural network weights. In this way, a flexible combination can be made with the flexibility and accuracy of neural network recognition, the regularizing effect of an arbitrarily chosen functional dependence, and a robust behavior against noise.

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