Thermodynamical Background of Regularization for Inverse Problems in Non-Destructive Evaluation

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Many methods in non-destructive evaluation image the samples interior structure from measured signals on the surface of a sample, like in photoacoustic imaging from measured pressure signals or in thermographic depth profiling from measured temperature signals. This imaging is an ill-posed or ill-conditioned problem, meaning that small errors in the measured surface signals can result in much larger errors in the reconstructed images. Typically the image reconstruction includes additional assumptions, such as the smoothness of the solution. This process is known as regularization, like truncated singular value decomposition (SVD) or Tikhonov regularization. The choice of an adequate regularization parameter which describes the trade-off between the original ill-conditioned problem and the additional assumptions (e.g. smoothness) is critical and has to be evaluated for every individual problem. For interior structures the information about the spatial pattern has to be transferred to the sample surface, where the signals are detected and the structures are reconstructed from the measured signals. The propagation to the sample surface reduces the available information for imaging, e.g. by scattering, attenuation, and diffusion. From statistical thermodynamics it is known that this information loss is for a macroscopic sample in a good approximation equal to the entropy production for the propagating wave from the samples interior to the surface. The entropy production is the dissipated energy divided by the temperature. We propose that by using the entropy production we get a physical background for choosing the regularization parameter for our imaging problem and no additional assumptions for regularization like smoothness or a minimal total variation of the reconstructions are necessary. These theoretical results are applied to compare photothermal and photoacoustic depth profiling. For thin coatings thermal and acoustic equations have to be coupled to model the measured surface dislocations and to get the adequate inverse problem for depth profiling.