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COMPUTATIONAL METHODS FOR INVERSE PROBLEMS

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ABSTRACT

Many problems in various fields of science and engineering are posed mathematically as inverse problems. In contrast to the more standard "forward problems", where the model describing the physical system is fully described, and the goal is to find the response due to given sources or known material and topology of the structure, the objective of an inverse problem is to find missing information on the model, based on some given information (acquired by measurements from sensors or by a priori design) on the response in space and/or time or to find optimal parameters or functions. Examples include, among many others:

(a) identifying damage in a structure;
(b) locating the epicenter of an earthquake from measurements on the ground;
(c) finding the optimal topology of an object that yields a desired function;
(d) finding the optimal melt cooling strategy (in space and time) in a crystal-growth process;
(e) identifying the main acoustic sources in a city;
(f) finding the optimal model and material parameters of a solid from experiments.

There is a rich literature on computational methods for inverse problems. Known methods include Linear Sampling Method, Arrival Time Imaging (Kirchhoff Migration), Time Reversal, Parameter/Topology-sensitivity based analysis, Stochastic (e.g. Bayesian) approaches, Full Waveform Inversion, the latter often relying on a gradient-based optimization and on the adjoint method, and more. Research in this area, aimed at devising new methods and improving existing ones, is very active, since inverse problems are notoriously hard; not only are they usually strongly nonlinear, but they are almost always ill-posed. In order to be effective, methods for the solution of inverse problems must be robust, efficient, and perform well even in the presence of noisy or uncertain data. Additional interesting and important challenges arise from the need for computationally-intensive solution methods. Examples include reduced order and surrogate models, and linear/nonlinear solvers.