Recent Trends on Nonlinear Filtering for Inverse Problems

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Abstract

Among the class of nonlinear particle filtering methods, the Ensemble Kalman Filter (EnKF) has gained recent attention for its use in solving inverse problems. We review the original method and discuss recent developments in particular in view of the limit for infinitely particles and extensions towards stability analysis and multi–objective optimization. We illustrate the performance of the method by using test inverse problems from the literature.

Keywords: Ensemble Kalman inversion, nonlinear filtering methods, inverse problems, multi-objective optimization, stability analysis

AMS subject classification: 65N21, 93E11, 35Q93, 37K35

1. Introduction

This review paper focuses on the Ensemble Kalman Filter applied to general inverse problems. In this context, some literature also uses the term Ensemble Kalman Inversion (EKI). Solving inverse problems or identification problems means determining parameters of a given model in order to obtain observable data. Due to the large range of applications, several approaches have been proposed in the literature to solve inverse problems. For instance, some well-known techniques rely on Bayesian formulation [1], but they can be extremely expensive. For this reason, efficient numerical schemes to solve the Bayesian inversion have been studied [2–4].

In this paper we are interested in solving inverse problems using a classical approach, i.e. relying on an optimization viewpoint, and in the numerical solution via the so-called particle methods. These can be divided into two classes of methods: the ones coming from particle swarm optimization, e.g. see [5] and the references therein, and the ensemble Kalman methods.

The EKI method belongs indeed to the class of particle methods and it is an iterative method for solving inverse problems. The method was originally introduced in [6] for unconstrained minimization problems, and recently extended also to the presence of different types of constraints [7–9]. The original EnKF has already been introduced more than ten years ago [10–13] as a discrete time method to estimate state variables and parameters of stochastic dynamical systems. The EKI method has become popular recently, because of the fact that it does not require derivatives of the underlying model for optimization but at the same time enjoys provable convergence results. Applications have been so far, in particular, in oceanography [14], reservoir modeling [15], weather forecasting [16], milling process [17], process control [18], geophysical applications [19–21], physics [22] and also machine learning [23–25]. The literature on Kalman filtering is very rich and we can not review this in detail here, but refer to the reference for further details. Our focus is on the reformulation of the EnKF for solving inverse problems as outlined below, in Section 1.2.

1.1. *Formulation of the ensemble Kalman inversion*

In order to present the mathematical formulation of the EKI method, we denote by $\mathcal{G} : X \to Y$ the given (nonlinear) forward operator between finite dimensional Hilbert spaces $X = \mathbb{R}^d$, $d \in N$, and

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problems be solved which have been beyond reach in former times It is the aim of this book to explore new developments in the field by way of discussion of selected topics from nonlinear analysis **Zeitschrift für Angewandte Mathematik und Mechanik. Volume 69, Number 1** H. Heinrich,G. Schmid,2022-03-21 Keine ausf hrliche Beschreibung f r Z ANGEW MATH MECH BD 69 1 ZAMM E BOOK verf gbar *Recent Trends in Systems Theory* Samuel D. Bedrosian,William A. Porter,1976 *Communications on Applied Nonlinear Analysis* ,2000 Hadamard-Type Fractional Differential Equations, Inclusions and Inequalities Bashir Ahmad,Ahmed Alsaedi,Sotiris K. Ntouyas,Jessada Tariboon,2017-03-16 This book focuses on the recent development of fractional differential equations integro differential equations and inclusions and inequalities involving the Hadamard derivative and integral Through a comprehensive study based in part on their recent research the authors address the issues related to initial and boundary value problems involving Hadamard type differential equations and inclusions as well as their functional counterparts The book covers fundamental concepts of multivalued analysis and introduces a new class of mixed initial value problems involving the Hadamard derivative and Riemann Liouville fractional integrals In later chapters the authors discuss nonlinear Langevin equations as well as coupled systems of Langevin equations with fractional integral conditions Focused and thorough this book is a useful resource for readers and researchers interested in the area of fractional calculus **IMU, ICM, Medals, Prizes, and Laureates** Ravi P. Agarwal,2025-10-19 The book begins with the formal establishment of the International Mathematical Union IMU and its purpose of promoting international cooperation in mathematics by supporting and assisting the international Congress of Mathematicians ICM every four years The book presents the most important features of each ICM from 1897 to 2022 including the history of various medals and awards particularly the Fields Medal which is regarded as one of the highest honors a mathematician can receive and has been described as the Nobel Prize of mathematics For each Laureate the book provides their family background a short description of the work that led to the award a history of academic jobs research conducted after receiving the award and a list of further honors and awards This book will stimulate all mathematicians especially students who think that mathematics is less rewarding compared to other disciplines Modern Tendencies in Engineering Sciences Seung Bok Choi,Yun Hae Kim,2014-02-27 Selected peer reviewed papers from the 2014 International Forum on Materials Processing Technology IFMPT 2014 January 18 19 2014 Guangzhou China and the 2014 International Conference on Sensors Instrument and Information Technology ICSIIT 2014 18 19 January 2014 Guangzhou China **Recent Trends in Robotics** Mohammad Jamshidi,J. Y. S. Luh,Mohsen Shahinpoor,1986 **Séminaire de mathématique** ,1982 *Notices of the American Mathematical Society* American Mathematical Society,1980 *Advanced Field-Effect Transistors* Dharmendra Singh Yadav,Shiromani Balmukund Rahi,Sukeshni Tirkey,2023-12-22 Advanced Field Effect Transistors Theory and Applications offers a fresh perspective on the design and analysis of advanced field effect transistor FET devices and their applications The text emphasizes both fundamental and new paradigms that are essential for upcoming advancement in the

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