



## Article

## Variational Estimation Methods for Sturm–Liouville Problems

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**Abstract:** In this paper, we are concerned with approach solutions for Sturm–Liouville problems (SLP) using variational problem (VP) formulation of regular SLP. The minimization problem (MP) is also set forth, and the connection between the solution of each formulation is then proved. Variational estimations (the variational equation associated through the Euler–Lagrange variational principle and Nehari’s method, shooting method and bisection method) and iterative variational methods (He’s method and HPM) for regular RSL are unitary presented in final part of the paper, which ends with applications.

**Keywords:** BVP nonlinear problems; variational methods; estimating nonlinearities; Green function

**MSC:** 34A12; 34A45



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## 1. Introduction

Nonlinearities are different from linear type by a function, an operator or a system that is nonlinear or is the case in which only some characteristics of it are known. The existence of the solution and the dependence of conditions for solving some classes of differential equations described by an operator is specified by the general framework of the Sturm–Liouville problem, with parametric conditions at the limit. The general framework of the Sturm–Liouville problem with parametric conditions at the limit is specified in the first part of the paper. The existence of the solution and the dependence of conditions is specified through the connection between the differential operator and Green’s function. Based on the properties of Green’s function, the operator used to analyze the behavior of the solution of the parameters given by the boundary conditions is specified. Variational problems derived from the initial RSLP are outlined with different type conditions in order to estimate the solution.

Let be the operator  $L = -\frac{d}{dx} \left[ p(x) \frac{d}{dx} \right] + p(x)$  as part of the regular Sturm–Liouville problem (RSL). The Sturm–Liouville (SL) problem expressed by the differential equation and the boundary conditions

$$a(x) \frac{d^2 u}{dx^2} + b(x) \frac{du}{dx} + c(x)u - \lambda d(x)u = 0, \quad (1)$$

$$\begin{aligned} B_1 : & a_1 u(a) + a_2 u'(a) = 0, \quad |a_1| + |a_2| \neq 0, a_1, a_2 \in \mathbb{R}, \\ B_2 : & b_1 u(b) + b_2 u'(b) = 0, \quad |b_1| + |b_2| \neq 0, b_1, b_2 \in \mathbb{R} \end{aligned} \quad (2)$$

could be written as

$$Lu + \lambda s(x)u = 0, \quad x \in (a, b) = I, \lambda \in \mathbb{R} \quad (3)$$

# Stable Methods For Illposed Variational Problems

**ML Morrison**



## **Stable Methods For Illposed Variational Problems:**

*Ill-posed Variational Problems and Regularization Techniques* Michel Thera, Rainer Tichatschke, 2012-12-06 This book presents recent developments in the field of ill posed variational problems and variational inequalities covering a large range of theoretical numerical and practical aspects The main topics are Regularization techniques for equilibrium and fixed point problems variational inequalities and complementary problems Links between approximation penalization and regularization Bundle methods nonsmooth optimization and regularization Error Bounds for regularized optimization problems Stable Methods for Ill-Posed Variational Problems Alexander Kaplan, Rainer Tichatschke, 1994-09-13 Iterative prox regularization methods for solving ill posed convex variational problems in Hilbert spaces are subject of this book A general framework is developed to analyse simultaneously procedures of regularization and successively refined discretization in connection with specific optimization methods for solving the discrete problems This allows an efficient control of the solution process as a whole In the first part of the book various methods for treating ill posed problems are presented including a study of the regularizing properties of a number of specific optimization algorithms In the second part a new class of multi step methods is introduced which is based on a generalization of the iterative prox regularization concept Compared with former methods these new methods permit a more effective use of rough approximations of the infinite dimensional problems and consequently an acceleration of the numerical process Special versions of these methods are given for ill posed convex semi infinite optimization problems and elliptic variational inequalities with weakly coercive operators including some problems in elasticity theory *Regularization Algorithms for Ill-Posed Problems* Anatoly B. Bakushinsky, Mikhail M. Kokurin, Mikhail Yu. Kokurin, 2018-02-05 This specialized and authoritative book contains an overview of modern approaches to constructing approximations to solutions of ill posed operator equations both linear and nonlinear These approximation schemes form a basis for implementable numerical algorithms for the stable solution of operator equations arising in contemporary mathematical modeling and in particular when solving inverse problems of mathematical physics The book presents in detail stable solution methods for ill posed problems using the methodology of iterative regularization of classical iterative schemes and the techniques of finite dimensional and finite difference approximations of the problems under study Special attention is paid to ill posed Cauchy problems for linear operator differential equations and to ill posed variational inequalities and optimization problems The readers are expected to have basic knowledge in functional analysis and differential equations The book will be of interest to applied mathematicians and specialists in mathematical modeling and inverse problems and also to advanced students in these fields Contents Introduction Regularization Methods For Linear Equations Finite Difference Methods Iterative Regularization Methods Finite Dimensional Iterative Processes Variational Inequalities and Optimization Problems **Regularization Methods for Ill-Posed Optimal Control Problems** Frank Pörner, 2018-10-04 Ill posed optimization problems appear in a wide range of mathematical applications and their numerical solution requires

the use of appropriate regularization techniques In order to understand these techniques a thorough analysis is inevitable The main subject of this book are quadratic optimal control problems subject to elliptic linear or semi linear partial differential equations Depending on the structure of the differential equation different regularization techniques are employed and their analysis leads to novel results such as rate of convergence estimates *Recent Advances in Optimization* Peter Gritzmann,Reiner Horst,Ekkehard Sachs,Rainer Tichatschke,2012-12-06 This book presents recent theoretical and practical aspects in the field of optimization and convex analysis The topics covered in this volume include Equilibrium models in economics Control theory and semi infinite programming Ill posed variational problems Global optimization Variational methods in image restoration Nonsmooth optimization Duality theory in convex and nonconvex optimization Methods for large scale problems *Iterative Methods for Approximate Solution of Inverse Problems* A.B. Bakushinsky,M.Yu. Kokurin,2007-09-28 This volume presents a unified approach to constructing iterative methods for solving irregular operator equations and provides rigorous theoretical analysis for several classes of these methods The analysis of methods includes convergence theorems as well as necessary and sufficient conditions for their convergence at a given rate The principal groups of methods studied in the book are iterative processes based on the technique of universal linear approximations stable gradient type processes and methods of stable continuous approximations Compared to existing monographs and textbooks on ill posed problems the main distinguishing feature of the presented approach is that it doesn't require any structural conditions on equations under consideration except for standard smoothness conditions This allows to obtain in a uniform style stable iterative methods applicable to wide classes of nonlinear inverse problems Practical efficiency of suggested algorithms is illustrated in application to inverse problems of potential theory and acoustic scattering The volume can be read by anyone with a basic knowledge of functional analysis The book will be of interest to applied mathematicians and specialists in mathematical modeling and inverse problems *Optimization* Van Hien Nguyen,Jean-Jacques Strodiot,Patricia Tossings,2012-12-06 The 9th Belgian French German Conference on Optimization has been held in Namur Belgium on September 7 11 1998 This volume is a collection of papers presented at this Conference Originally this Conference was a French German Conference but this year in accordance with the organizers wishes a third country Belgium has joined the founding members of the Conference Hence the name Belgian French German Conference on Optimization Since the very beginning the purpose of these Conferences has been to bring together researchers working in the area of Optimization and particularly to encourage young researchers to present their work Most of the participants come from the organizing countries However the general tendency is to invite outside researchers to attend the meeting So this year among the 101 participants at this Conference twenty researchers came from other countries The general theme of the Conference is everything that concerns the area of Optimization without specification of particular topics So theoretical aspects of Optimization in addition to applications and algorithms of Optimization will be developed However and this point

was very important for the organizers the Conference must retain its convivial character No more than two parallel sessions are organized This would allow useful contacts between researchers to be promoted The editors express their sincere thanks to all those who took part in this Conference Their invaluable discussions have made this volume possible

**Equilibrium Problems** Lam Quoc Anh, Phan Quoc Khanh, Nguyen Hong Quan, 2025-09-26 This book is a systematic and comprehensive exposition of the state of the art research results in the literature on equilibrium problems The book describes the highest level research and reflects a current picture of results in the literature on the three topics in a very central place of the general theory of equilibrium problems existence stability and approximation together with their particular cases and numerous applications It is intended to serve as both introductory and deep courses for graduate students or as useful materials for researchers studying aspects of optimization and equilibrium problems or more generally working on inter discipline such as mathematical economics operations research and management or even in various areas of science and technology In providing profound knowledge of recent research this book has advantages over existing recent books focused on equilibrium problems and variational relation problems and may also be suitable for readers preparing deep and comprehensive graduate courses

**Nonlinear Ill-posed Problems of Monotone Type** Yakov Alber, Irina Ryazantseva, 2006-02-23 Interest in regularization methods for ill posed nonlinear operator equations and variational inequalities of monotone type in Hilbert and Banach spaces has grown rapidly over recent years Results in the field over the last three decades previously only available in journal articles are comprehensively explored with particular attention given to applications of regularization methods as well as to practical methods used in computational analysis

**Encyclopedia of Optimization** Christodoulos A. Floudas, Panos M. Pardalos, 2008-09-04 The goal of the Encyclopedia of Optimization is to introduce the reader to a complete set of topics that show the spectrum of research the richness of ideas and the breadth of applications that has come from this field The second edition builds on the success of the former edition with more than 150 completely new entries designed to ensure that the reference addresses recent areas where optimization theories and techniques have advanced Particularly heavy attention resulted in health science and transportation with entries such as Algorithms for Genomics Optimization and Radiotherapy Treatment Design and Crew Scheduling

**Regularization of Ill-Posed Problems by Iteration Methods** S.F. Gilyazov, N.L. Gol'dman, 2013-04-17 Iteration regularization i.e. utilization of iteration methods of any form for the stable approximate solution of ill posed problems is one of the most important but still insufficiently developed topics of the new theory of ill posed problems In this monograph a general approach to the justification of iteration regularization algorithms is developed which allows us to consider linear and nonlinear methods from unified positions Regularization algorithms are the classical iterative methods steepest descent methods conjugate direction methods gradient projection methods etc complemented by the stopping rule depending on level of errors in input data They are investigated for solving linear and nonlinear operator equations in Hilbert spaces Great attention is given to

the choice of iteration index as the regularization parameter and to estimates of errors of approximate solutions Stabilizing properties such as smoothness and shape constraints imposed on the solution are used On the basis of these investigations we propose and establish efficient regularization algorithms for stable numerical solution of a wide class of ill posed problems In particular descriptive regularization algorithms utilizing a priori information about the qualitative behavior of the sought solution and ensuring a substantial saving in computational costs are considered for model and applied problems in nonlinear thermophysics The results of calculations for important applications in various technical fields a continuous casting the treatment of materials and perfection of heat protective systems using laser and composite technologies are given

**Theory of Linear Ill-Posed Problems and its Applications** Valentin K. Ivanov,Vladimir V. Vasin,Vitalii P.

Tanana,2013-02-18 This monograph is a revised and extended version of the Russian edition from 1978 It includes the general theory of linear ill posed problems concerning e g the structure of sets of uniform regularization the theory of error estimation and the optimality method As a distinguishing feature the book considers ill posed problems not only in Hilbert but also in Banach spaces It is natural that since the appearance of the first edition considerable progress has been made in the theory of inverse and ill posed problems as well as in its applications To reflect these accomplishments the authors included additional material e g comments to each chapter and a list of monographs with annotations Systems and Networks: Invited and contributed papers Uwe Helmke,Reinhard Mennicken,Josef Saurer,1994 Recent Developments in Optimization Roland Durier,Christian Michelot,2012-12-06 The main objective of this volume is to provide a presentation and discussion of recent developments in optimization and related fields Equal emphasis is given to theoretical and practical studies All the papers in this volume contain original results except two of them which are survey contributions They deal with a wide range of topics such as optimization and variational inequalities sensitivity and stability analysis control theory convex and nonsmooth analysis and numerical methods *Control and Estimation of Distributed Parameter Systems* W. Desch,Franz Kappel,K. Kunisch,1998-03-24 Consisting of 23 refereed contributions this volume offers a broad and diverse view of current research in control and estimation of partial differential equations Topics addressed include but are not limited to control and stability of hyperbolic systems related to elasticity linear and nonlinear control and identification of nonlinear parabolic systems exact and approximate controllability and observability Pontryagin's maximum principle and dynamic programming in PDE and numerics pertinent to optimal and suboptimal control problems This volume is primarily geared toward control theorists seeking information on the latest developments in their area of expertise It may also serve as a stimulating reader to any researcher who wants to gain an impression of activities at the forefront of a vigorously expanding area in applied mathematics **Recent Advances in Optimization** Alberto Seeger,2006-01-26 The contributions appearing in this book give an overview of recent research done in optimization and related areas such as optimal control calculus of variations and game theory They do not only address abstract issues of optimization theory but

are also concerned with the modeling and computer resolution of specific optimization problems arising in industry and applied sciences

*Numerical Treatment of Partial Differential Equations* Christian Grossmann, Hans-G. Roos, Martin Stynes, 2007-10-04 This book deals with discretization techniques for partial differential equations of elliptic parabolic and hyperbolic type It provides an introduction to the main principles of discretization and gives a presentation of the ideas and analysis of advanced numerical methods in the area The book is mainly dedicated to finite element methods but it also discusses difference methods and finite volume techniques Coverage offers analytical tools properties of discretization techniques and hints to algorithmic aspects It also guides readers to current developments in research

Methods for Solving Incorrectly Posed Problems V.A. Morozov, 2012-12-06 Some problems of mathematical physics and analysis can be formulated as the problem of solving the equation  $AF = f$  where  $A: D(A) \subset U \rightarrow F$  is an operator with a non empty domain of definition  $D$  in a metric space  $U$  with range in a metric space  $F$  The metrics  $A$  on  $U$  and  $F$  will be denoted by  $P$  and  $P$  respectively Relative  $u \in F$  to the twin spaces  $U$  and  $F$  J Hadamard P 06 gave the following definition of correctness the problem 1 is said to be well posed correct properly posed if the following conditions are satisfied 1 The range of the value  $Q$  of the operator  $A$  coincides with  $A^{-1}f$  solvability condition 2 The equality  $\|Au\|_F \leq \|u\|_U$  for any  $u \in D(A)$  implies the  $L^2$  equality  $\|u\|_U \leq \|f\|_F$  uniqueness condition 1 2 3 The inverse operator  $A^{-1}$  is continuous on  $F$  stability condition Any reasonable mathematical formulation of a physical problem requires that conditions 1 3 be satisfied That is why Hadamard postulated that any ill posed improperly posed problem that is to say one which does not satisfy conditions 1 3 is non physical Hadamard also gave the now classical example of an ill posed problem namely the Cauchy problem for the Laplace equation

*Numerical Methods for Solving Inverse Problems of Mathematical Physics* A. A. Samarskii, Petr N. Vabishchevich, 2008-08-27 The main classes of inverse problems for equations of mathematical physics and their numerical solution methods are considered in this book which is intended for graduate students and experts in applied mathematics computational mathematics and mathematical modelling

**Inverse Problems, Tomography, and Image Processing** Alexander G. Ramm, 2013-11-11 Proceedings of Sessions from the First Congress of the International Society for Analysis Applications and Computing held in Newark Delaware June 2 6 1997

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