

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



**Citation:** Cipu, E.C.; Barbu, C.D. Variational Estimation Methods for Sturm–Liouville Problems. *Mathematics* **2022**, *10*, 3728. <https://doi.org/10.3390/math10203728>

Academic Editors: Simeon Reich and Alessio Pomponio

Received: 30 July 2022

Accepted: 7 October 2022

Published: 11 October 2022

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

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

$$\begin{aligned} B_1 : & \alpha_1 u(a) + \alpha_2 u'(a) = 0, \quad |\alpha_1| + |\alpha_2| \neq 0, \alpha_1, \alpha_2 \in \mathbb{R}, \\ B_2 : & \beta_1 u(b) + \beta_2 u'(b) = 0, \quad |\beta_1| + |\beta_2| \neq 0, \beta_1, \beta_2 \in \mathbb{R} \end{aligned} \quad (2)$$

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

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

**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 Stable Methods for III-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 **Ill-posed Variational**

**Problems and Regularization Techniques** Michel Thera, 1999-11-17 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 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 **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 **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 **Systems and Networks: Invited and contributed papers** Uwe Helmke, Reinhard Mennicken, Josef Saurer, 1994 **Stable Operators in Analysis and Optimization** Vadim

Azhmyakov, 2005 The main purpose of this book is to provide an advanced account of some aspects of differentiable stable operators in Banach and Hilbert spaces The theory of linear and nonlinear stable operators is presented in a systematic way and possible applications are described The book is useful to graduate students and researchers SIAM Journal on Control and Optimization Society for Industrial and Applied Mathematics, 2008 From Convexity to Nonconvexity R.P.

Gilbert, Panagiotis D. Panagiotopoulos, Panos M. Pardalos, 2001-09-30 The book contains a collection of invited papers dedicated to the memory of two great mathematicians Gaetano Fichera and Panagis Panagiotopoulos The theme of the collection is centered around the seminal research of G Fichera on the Signorini problem hemivariational inequalities pioneered by Panagiotopoulos nonsmooth global optimization and regularity results for variational inequalities Audience The

book is addressed to faculty graduate students and researchers in mathematical programming and engineering **Journal of Nonlinear and Convex Analysis**, 2005 **Siberian Advances in Mathematics**, 1992 **Parametric Optimization and Related Topics**, 1995 Optimization Theory and Its Application Lou Caccetta, 2001 **Solutions of Ill-posed Problems** Andreï Nikolaevich Tikhonov, Vasilii Iĭkovlevich Arsenin, 1977 **Nonlinear Ill-Posed Problems** A.N. Tikhonov, A.S. Leonov, A.G. Yagola, 1998

Professor A N Tikhonov was the founder of nonlinear ill posed problem theory This two volume book introduces the reader to the theory and shows its applications in the natural sciences The first volume introduces the foundations of the theory and provides the background necessary for the design of numerical methods The second volume presents the finite dimensional variants and modification of these methods to help readers use current computer software It considers applications in linear algebra vibrational spectroscopy astrophysics and medicine

*Discussiones Mathematicae*, 2006 **Nonlinear Ill-posed Problems** Andreï Nikolaevich Tikhonov, A. S. Leonov, Anatoliĭ Grigor'evich Āgola, 1998 *Linear Semi-Infinite Optimization* Miguel A. Goberna, Marco A. López, 1998-03-11 A linear semi infinite program is an optimization problem with linear objective functions and linear constraints in which either the number of unknowns or the number of constraints is finite The many direct applications of linear semi infinite optimization or programming have prompted considerable and increasing research effort in recent years The authors aim is to communicate the main theoretical ideas and applications techniques of this fascinating area from the perspective of convex analysis The four sections of the book cover Modelling with primal and dual problems the primal problem space of dual variables the dual problem Linear semi infinite systems existence theorems alternative theorems redundancy phenomena geometrical properties of the solution set Theory of linear semi infinite programming optimality duality boundedness perturbations well posedness Methods of linear semi infinite programming an overview of the main numerical methods for primal and dual problems Exercises and examples are provided to illustrate both theory and applications The reader is assumed to be familiar with elementary calculus linear algebra and general topology An appendix on convex analysis is provided to ensure that the book is self contained Graduate students and researchers wishing to gain a deeper understanding of the main ideas behind the theory of linear optimization will find this book to be an essential text **Methods for Solving Incorrectly Posed Problems** Vladimir Alekseevich Morozov, 1984

Some problems of mathematical physics and analysis can be formulated as the problem of solving the equation  $f \in F, Au = f$  where  $A: D \subset U \rightarrow F$  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  $F$  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  $A \cdot F$  solvability condition 2 The equality  $Au = Au$  for any  $u \in D$  implies the  $\|u\|_U \leq \|u\|_F$  equality  $u = u$  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.

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