Numerical Solution of Integral Equations for Reliability Quantification

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Key Words—Failure and repair intensities, Integral equation.

Reader Aids—
Purpose: Report a mathematical technique
Special math needed for explanations: Advanced probability, Advanced numerical analysis
Special math needed to use results: Same
Results useful to: Reliability theoreticians

Abstract—This paper gives a numerical method for solving a linear system of integral equations whose solution is the set of unconditional failure and repair intensities of a component, where the component life and repair times are arbitrarily distributed. Our method gives a sequence of solutions that converges to the true solution of the system of integral equations. An example illustrates our method.

1. INTRODUCTION

Fault tree analysis is a widely used technique for evaluating the reliability and safety of complex systems. The methods by Vesely [1] and Inagaki & Henley [2] can perform rigorous probabilistic evaluation of top-events for s-coherent and non-coherent systems, respectively. Both of these methods assume that unconditional failure and repair intensities of relevant components in the system are known.

The unconditional failure and repair intensities of a component are given as solutions to a linear system of integral equations [3, p 193] that is difficult to solve analytically except when the component life and repair times are exponentially distributed. This paper gives a numerical method for solving the linear system of integral equations when the component life and repair times are arbitrarily distributed. A sequence of solutions obtained by our method converges to the true solution of the integral equations. This paper uses a rather abstract mathematics in developing the theory of our method of solution. In executing our approach, however, we only have to solve a matrix equation. A conventional method such as Gauss-Seidel directly applies to solve the matrix equation.

2. NOTATION, NOMENCLATURE, AND ASSUMPTIONS

Notation

E_0 event that the component was up and new at the initial time ($t = 0$)

$w(t)$ unconditional failure intensity of the component; viz, $w(t) = \lim_{dt \to 0} \frac{1}{dt} \Pr\{\text{component is up at time } t \text{ and fails in } (t, t + dt) | E_0\}$

$v(t)$ unconditional repair intensity of the component; viz. $v(t) = \lim_{dt \to 0} \frac{1}{dt} \Pr\{\text{component is under repair at time } t \text{ and the repair completes in } (t, t + dt) | E_0\}$

X_i random length of working period i of the component

Y_i random length of repair period i of the component

$f(t), F(t)$ common pdf, Cdf for X_i

$g(t), G(t)$ common pdf, Cdf for Y_i

A_a Volterra operator; defined in the text

I identity operator such that $I\{a(t)\} = a(t)$; or identity matrix

$C[0, T]$ Banach space of real-valued functions that are continuous on the interval $[0, T]$

P_n bounded linear projections, ie, $P_n^2 = P_n$, of $C[0, T]$ onto n-dimensional subspace S_n of $C[0, T]$

$\{e_i(t): i = 1, \ldots, n\}$ basis for n-dimensional subspace S_n; viz, $P_n z \in S_n$ for $z \in C[0, T]$, and $P_n z$ is represented as $P_n z = e_1^*(z)e_1(t) + \ldots + e_n^*(z)e_n(t)$

$e_i^*(z)$ the $e_i(t)$-component of $P_n z$ when $P_n z$ is expanded as a linear combination of $e_1(t), \ldots, e_n(t)$

$\|\cdot\|$ norm; vector norm and matrix norm are defined in the text

$\text{col}(x_1, \ldots, x_n)$ n-dimensional column vector with elements $x_1, \ldots, x_n$

δ_{ij} Kronecker delta; viz, $\delta_{ij} = 1$ for $i = j$, $\delta_{ij} = 0$ for $i \neq j$

F_n $n \times n$ matrix with $e_i^* A_f e_j$ as its (i, j)-element

G_n $n \times n$ matrix with $e_i^* A_g e_j$ as its (i, j)-element

c, d $c = \text{col}(c_1, \ldots, c_n)$, $d = \text{col}(d_1, \ldots, d_n)$

h $\text{col}(e_1^* f, \ldots, e_n^* f)$

λ, μ constant failure and repair rates

Nomenclature

spectral radius — Let $\varrho_i (i = 1, \ldots, n)$ be eigenvalues of an $n \times n$ matrix A. The spectral radius $\varrho(A)$ of matrix A is $\varrho(A) = \max\{|\varrho_i|: i = 1, \ldots, n\}$

acceleration parameter — parameters that are chosen to make the convergence interative process rapid

Assumptions

1. The component starts working at the initial time ($t = 0$). The component is perfect (up and new) at $t = 0$.
2. Repair begins immediately upon failure of the component.

Numerical Solution Of Integral Equations

Christopher T. H. Baker

Numerical Solution Of Integral Equations:

The Numerical Solution of Integral Equations of the Second Kind Kendall E. Atkinson,1997-06-28 This book provides an extensive introduction to the numerical solution of a large class of integral equations **Numerical Solution of Integral Equations** Michael A. Golberg,2013-11-11 In 1979 I edited Volume 18 in this series Solution Methods for Integral Equations Theory and Applications Since that time there has been an explosive growth in all aspects of the numerical solution of integral equations By my estimate over 2000 papers on this subject have been published in the last decade and more than 60 books on theory and applications have appeared In particular as can be seen in many of the chapters in this book integral equation techniques are playing an increas ingly important role in the solution of many scientific and engineering problems For instance the boundary element method discussed by Atkinson in Chapter 1 is becoming an equal partner with finite element and finite difference techniques for solving many types of partial differential equations Obviously in one volume it would be impossible to present a complete picture of what has taken place in this area during the past ten years Consequently we have chosen a number of subjects in which significant advances have been made that we feel have not been covered in depth in other books For instance ten years ago the theory of the numerical solution of Cauchy singular equations was in its infancy Today as shown by Golberg and Elliott in Chapters 5 and 6 the theory of polynomial approximations is essentially complete although many details of practical implementation remain to be worked out **The Application and Numerical Solution of Integral Equations** R.S. Anderssen,F.R. de Hoog,M.A. Lukas,1980-03-31 This publication reports the proceedings of a one day seminar on The Application and Numerical Solution of Integral Equations held at the Australian National University on Wednesday November 29 1978 It was organized by the Computing Research Group Australian National University and the Division of Mathematics and Statistics CSIRO Due to unforeseen circumstances Dr M L Dow was unable to participate At short notice Professor D Elliott reviewed Cauchy singular integral equations but a paper on same is not included in these proceedings The interested reader is referred to the recent translation of V V Ivanov The Theory of Approximate Methods and their Application to the Numerical Solution of Singular Integral Equations Noordhoff International Publishers Leyden 1976 An attempt was made to structure the program to the extent that the emphasis was on the numerical solution of integral equations for which known applications exist along with explanations of how and why integral equation formalisms arise In addition the programme reflected the broad classification of most integral equations as either singular or non singular as either Fredholm or Volterra and as either first or second kind **The Numerical Treatment of Integral Equations** Christopher T. H. Baker,1977 This book is concerned with the numerical analysis of integral equations We are not principally concerned with the abstract theory of integral equations nor with applications of mathematics where integral equations arise but the first chapter is devoted to a review of the theory of integral equations The survey of certain aspects of numerical analysis in chapter 2 is intended to emphasize various topics

which are of relevance in the study of numerical methods for integral equations **Numerical Solution of Integral Equations** Frank C. Helwig,1950 <u>The Numerical Solution of Integral Equations</u> Helen Mary Williams,1978 *The Numerical Solution of Volterra Equations* Hermann Brunner,Pieter Jacobus Houwen,1986 This monograph presents the theory and modern numerical analysis of Volterra integral and integro differential equations including equations with weakly singular kernels While the research worker will find an up to date account of recent developments of numerical methods for such equations including an extensive bibliography the authors have tried to make the book accessible to the non specialist possessing only a limited knowledge of numerical analysis After an introduction to the theory of Volterra equations and to numerical integration the book covers linear methods and Runge Kutta methods collocation methods based on polynomial spline functions stability of numerical methods and it surveys computer programs for Volterra integral and integro differential equations **Solution Methods for Integral Equations** M. A. Goldberg,2013-11-21 **On the Numerical Solution of Integral Equations** Gorakh Prasad,1924 **A Course on Integral Equations with Numerical Analysis** Tofigh Allahviranloo,Armin Esfandiari,2021-10-30 This book suggests that the numerical analysis subjects matter are the important tools of the book topic because numerical errors and methods have important roles in solving integral equations Therefore all needed topics including a brief description of interpolation are explained in the book The integral equations have many applications in the engineering medical and economic sciences so the present book contains new and useful materials about interval computations including interval interpolations that are going to be used in interval integral equations The concepts of integral equations are going to be discussed in two directions analytical concepts and numerical solutions which both are necessary for these kinds of dynamic systems The differences between this book with the others are a full discussion of error topics and also using interval interpolations concepts to obtain interval integral equations All researchers and students in the field of mathematical computer and also engineering sciences can benefit the subjects of the book **Numerical Solution of Singular Integral Equations** Apostolos Gerasoulis,Robert Vichnevetsky,1984 **Weighted Polynomial Approximation and Numerical Methods for Integral Equations** Peter Junghanns,Giuseppe Mastroianni,Incoronata Notarangelo,2021-08-10 The book presents a combination of two topics one coming from the theory of approximation of functions and integrals by interpolation and quadrature respectively and the other from the numerical analysis of operator equations in particular of integral and related equations The text focusses on interpolation and quadrature processes for functions defined on bounded and unbounded intervals and having certain singularities at the endpoints of the interval as well as on numerical methods for Fredholm integral equations of first and second kind with smooth and weakly singular kernel functions linear and nonlinear Cauchy singular integral equations and hypersingular integral equations The book includes both classic and very recent results and will appeal to graduate students and researchers who want to learn about the approximation of functions and the numerical solution of operator equations in

particular integral equations **Linear Integral Equations** Rainer Kress,2013-12-04 This book combines theory applications and numerical methods and covers each of these fields with the same weight In order to make the book accessible to mathematicians physicists and engineers alike the author has made it as self contained as possible requiring only a solid foundation in differential and integral calculus The functional analysis which is necessary for an adequate treatment of the theory and the numerical solution of integral equations is developed within the book itself Problems are included at the end of each chapter For this third edition in order to make the introduction to the basic functional analytic tools more complete the Hahn Banach extension theorem and the Banach open mapping theorem are now included in the text The treatment of boundary value problems in potential theory has been extended by a more complete discussion of integral equations of the first kind in the classical Holder space setting and of both integral equations of the first and second kind in the contemporary Sobolev space setting In the numerical solution part of the book the author included a new collocation method for two dimensional hypersingular boundary integral equations and a collocation method for the three dimensional Lippmann Schwinger equation The final chapter of the book on inverse boundary value problems for the Laplace equation has been largely rewritten with special attention to the trilogy of decomposition iterative and sampling methods Reviews of earlier editions This book is an excellent introductory text for students scientists and engineers who want to learn the basic theory of linear integral equations and their numerical solution Math Reviews 2000 This is a good introductory text book on linear integral equations It contains almost all the topics necessary for a student The presentation of the subject matter is lucid clear and in the proper modern framework without being too abstract ZbMath 1999 Novel Methods for Solving Linear and Nonlinear Integral Equations Santanu Saha Ray,Prakash Kumar Sahu,2018-12-07 This book deals with the numerical solution of integral equations based on approximation of functions and the authors apply wavelet approximation to the unknown function of integral equations The book s goal is to categorize the selected methods and assess their accuracy and efficiency **Aspects of the Numerical Solution of Integral Equations** Janet Aldyth Thomas,University of Manchester. Department of Mathematics, Pure and Applied,1975 *Treatment of Integral Equations by Numerical Methods* London Mathematical Society,1982 **Computational Methods for Integral Equations** L. M. Delves,J. L. Mohamed,1985 This textbook provides a readable account of techniques for numerical solutions **Numerical Solution of Integral Equations** M. C. Cook,1974 **Ordinary Differential Equations and Integral Equations** C.T.H. Baker,G. Monegato,G. vanden Berghe,2001-06-20 homepage sac cam na2000 index html7 Volume Set now available at special set price This volume contains contributions in the area of differential equations and integral equations Many numerical methods have arisen in response to the need to solve real life problems in applied mathematics in particular problems that do not have a closed form solution Contributions on both initial value problems and boundary value problems in ordinary differential equations appear in this volume Numerical methods for initial value problems in ordinary differential

equations fall naturally into two classes those which use one starting value at each step one step methods and those which are based on several values of the solution multistep methods John Butcher has supplied an expert s perspective of the development of numerical methods for ordinary differential equations in the 20th century Rob Corless and Lawrence Shampine talk about established technology namely software for initial value problems using Runge Kutta and Rosenbrock methods with interpolants to fill in the solution between mesh points but the slant is new based on the question How should such software integrate into the current generation of Problem Solving Environments Natalia Borovykh and Marc Spijker study the problem of establishing upper bounds for the norm of the nth power of square matrices The dynamical system viewpoint has been of great benefit to ODE theory and numerical methods Related is the study of chaotic behaviour Willy Govaerts discusses the numerical methods for the computation and continuation of equilibria and bifurcation points of equilibria of dynamical systems Arieh Iserles and Antonella Zanna survey the construction of Runge Kutta methods which preserve algebraic invariant functions Valeria Antohe and Ian Gladwell present numerical experiments on solving a Hamiltonian system of H non and Heiles with a symplectic and a nonsymplectic method with a variety of precisions and initial conditions Stiff differential equations first became recognized as special during the 1950s In 1963 two seminal publications laid to the foundations for later development Dahlquist s paper on A stable multistep methods and Butcher s first paper on implicit Runge Kutta methods Ernst Hairer and Gerhard Wanner deliver a survey which retraces the discovery of the order stars as well as the principal achievements obtained by that theory Guido Vanden Berghe Hans De Meyer Marnix Van Daele and Tanja Van Hecke construct exponentially fitted Runge Kutta methods with s stages Differential algebraic equations arise in control in modelling of mechanical systems and in many other fields Jeff Cash describes a fairly recent class of formulae for the numerical solution of initial value problems for stiff and differential algebraic systems Shengtai Li and Linda Petzold describe methods and software for sensitivity analysis of solutions of DAE initial value problems Again in the area of differential algebraic systems Neil Biehn John Betts Stephen Campbell and William Huffman present current work on mesh adaptation for DAE two point boundary value problems Contrasting approaches to the question of how good an approximation is as a solution of a given equation involve i attempting to estimate the actual error i e the difference between the true and the approximate solutions and ii attempting to estimate the defect the amount by which the approximation fails to satisfy the given equation and any side conditions The paper by Wayne Enright on defect control relates to carefully analyzed techniques that have been proposed both for ordinary differential equations and for delay differential equations in which an attempt is made to control an estimate of the size of the defect Many phenomena incorporate noise and the numerical solution of   *Numerical Solution of Integral Equations* A. L. Ganado,1968

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