

Article

Numerical Solution of Nonlinear Problems with Multiple Roots Using Derivative-Free Algorithms

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Abstract: In the study of systems' dynamics the presence of symmetry dramatically reduces the complexity, while in chemistry, symmetry plays a central role in the analysis of the structure, bonding, and spectroscopy of molecules. In a more general context, the principle of equivalence, a principle of local symmetry, dictated the dynamics of gravity, of space-time itself. In certain instances, especially in the presence of symmetry, we end up having to deal with an equation with multiple roots. A variety of optimal methods have been proposed in the literature for multiple roots with known multiplicity, all of which need derivative evaluations in the formulations. However, in the literature, optimal methods without derivatives are few. Motivated by this feature, here we present a novel optimal family of fourth-order methods for multiple roots with known multiplicity, which do not use any derivative. The scheme of the new iterative family consists of two steps, namely Traub-Steffensen and Traub-Steffensen-like iterations with weight factor. According to the Kung-Traub hypothesis, the new algorithms satisfy the optimality criterion. Taylor's series expansion is used to examine order of convergence. We also demonstrate the application of new algorithms to real-life problems, i.e., Van der Waals problem, Manning problem, Planck law radiation problem, and Kepler's problem. Furthermore, the performance comparisons have shown that the given derivative-free algorithms are competitive with existing optimal fourth-order algorithms that require derivative information.

Keywords: multiple roots; convergence; nonlinear equations; derivative-free method

MSC: 49M15; 65H05; 41A25



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1. Introduction

Simple systems often embed a good amount of symmetry. Take for instance the characteristic polynomial (ChP) of hydrocarbons [1]. Considering 3 cases here, propane (ChP is $x^3 - 2x$), normal butane (ChP is $x^4 - 3x^2 + x$) and isobutane (ChP is $x^4 - 3x^2$), one should easily notice that the highest symmetry is in isobutane. At the same time, isobutane is the one having multiple roots in the characteristic polynomial. Same symmetry is responsible for the presence of the multiple roots in the ChP of 2,2,4,4-Tetramethylpentane (ChP is $x^9 - 8x^7 + 15x^5$, see a₂₅ in [2]). One should notice that, in the selected cases, the multiple root is banal ($x = 0$); however, in general, in more complex cases, the multiple root is not any more banal.

Much research has been conducted on the solution of nonlinear equations and systems of nonlinear equations. There are numerous publications on the topic, including those given in reference [3–10], and Traub's book [11] has a whole chapter devoted to

Numerical Solution Of Nonlinear Problems

**James McDonough Ortega, Werner Carl
Rheinboldt**



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The Numerical Solution of Nonlinear Problems Christopher T. H. Baker, Chris Phillips, 1981 **Numerical Solution of Nonlinear Equations** E.L. Allgöwer, K. Glashoff, H.-O. Peitgen, 2006-11-14 **Numerical solution of nonlinear problems** James M. Ortega, 1970 **Numerical Solution of Systems of Nonlinear Algebraic Equations** George D. Byrne, Charles A. Hall, 2014-05-10

Numerical Solution of Systems of Nonlinear Algebraic Equations contains invited lectures of the NSF CBMS Regional Conference on the Numerical Solution of Nonlinear Algebraic Systems with Applications to Problems in Physics Engineering and Economics held on July 10 14 1972 This book is composed of 10 chapters and begins with the concepts of nonlinear algebraic equations in continuum mechanics The succeeding chapters deal with the numerical solution of quasilinear elliptic equations the nonlinear systems in semi infinite programming and the solution of large systems of linear algebraic equations These topics are followed by a survey of some computational techniques for the nonlinear least squares problem The remaining chapters explore the problem of nonlinear functional minimization the modification methods and the computer oriented algorithms for solving system These chapters also examine the principles of contractor theory of solving equations This book will prove useful to undergraduate and graduate students **Numerical Solutions of Nonlinear Problems** James M. Ortega, Werner C. Rheinboldt, 1970 Numerical Methods for Nonlinear Partial Differential Equations Sören Bartels, 2015-01-19

The description of many interesting phenomena in science and engineering leads to infinite dimensional minimization or evolution problems that define nonlinear partial differential equations While the development and analysis of numerical methods for linear partial differential equations is nearly complete only few results are available in the case of nonlinear equations This monograph devises numerical methods for nonlinear model problems arising in the mathematical description of phase transitions large bending problems image processing and inelastic material behavior For each of these problems the underlying mathematical model is discussed the essential analytical properties are explained and the proposed numerical method is rigorously analyzed The practicality of the algorithms is illustrated by means of short implementations *Numerical Solutions of Nonlinear Problems* James M. Ortega, Werner C. Rheinboldt, 1970

Numerical Solutions of Nonlinear Problems James M. Ortega, Werner C. Rheinboldt, 1970 **Numerical Methods for Unconstrained Optimization and Nonlinear Equations** J. E. Dennis, Jr., Robert B. Schnabel, 1996-12-01

This book has become the standard for a complete state of the art description of the methods for unconstrained optimization and systems of nonlinear equations Originally published in 1983 it provides information needed to understand both the theory and the practice of these methods and provides pseudocode for the problems The algorithms covered are all based on Newton's method or quasi Newton methods and the heart of the book is the material on computational methods for multidimensional unconstrained optimization and nonlinear equation problems The republication of this book by SIAM is driven by a continuing demand for specific and sound advice on how to solve real problems The level of presentation is consistent

throughout with a good mix of examples and theory making it a valuable text at both the graduate and undergraduate level It has been praised as excellent for courses with approximately the same name as the book title and would also be useful as a supplemental text for a nonlinear programming or a numerical analysis course Many exercises are provided to illustrate and develop the ideas in the text A large appendix provides a mechanism for class projects and a reference for readers who want the details of the algorithms Practitioners may use this book for self study and reference For complete understanding readers should have a background in calculus and linear algebra The book does contain background material in multivariable calculus and numerical linear algebra

Studies in Numerical Analysis 2 James McDonough Ortega, Werner Carl Rheinboldt, 1970

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Numerical Solution of Nonlinear Problems James M. Ortega, 1970

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Computational Solution of Nonlinear Systems of Equations Eugene L. Allgower, Kurt Georg, 1990-04-03 Nonlinear equations arise in essentially every branch of modern science engineering and mathematics However in only a very few special cases is it possible to obtain useful solutions to nonlinear equations via analytical calculations As a result many scientists resort to computational methods This book contains the proceedings of the Joint AMS SIAM Summer Seminar

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Wavelet Numerical Method and Its Applications in Nonlinear Problems You-He

Zhou,2021-03-09 This book summarizes the basic theory of wavelets and some related algorithms in an easy to understand language from the perspective of an engineer rather than a mathematician In this book the wavelet solution schemes are systematically established and introduced for solving general linear and nonlinear initial boundary value problems in engineering including the technique of boundary extension in approximating interval bounded functions the calculation method for various connection coefficients the single point Gaussian integration method in calculating the coefficients of wavelet expansions and unique treatments on nonlinear terms in differential equations At the same time this book is supplemented by a large number of numerical examples to specifically explain procedures and characteristics of the method as well as detailed treatments for specific problems Different from most of the current monographs focusing on the basic theory of wavelets it focuses on the use of wavelet based numerical methods developed by the author over the years Even for the necessary basic theory of wavelet in engineering applications this book is based on the author s own understanding in plain language instead of a relatively difficult professional mathematical description This book is very suitable for students researchers and technical personnel who only want to need the minimal knowledge of wavelet method to solve specific problems in engineering

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