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To The Computational Mathematics in Nonlinear Equations Used in Mathematical Modeling

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Abstract

The domains of engineering, physics, chemistry, biosciences, and many more find it in several real-world scenarios. An implicit uncertainty in a scientific or engineering equation really creates a root-finding issue. Furthermore, two numerical methods for addressing root-finding problems in nonlinear equations with the presumption of a solution have been discussed, in addition to the bisection technique and the Newton-Rhapson method. Many of these iterative methods are really multi-stage iterative processes including predictor and corrector stages. Computational mathematics is a branch of mathematics concerned with the development and use of mathematical models, algorithms, and procedures for the goal of solving complex problems in many different academic domains, such as science, engineering, finance, and others. An algorithm is just a set of rules on how to do something. Finding the roots of the mathematical function is now possible using techniques such as the Newton-Raphson method. An essential use of computational mathematics is its integration with scientific investigation. By simulating real-world events in virtual environments, researchers may study how natural systems function.

Keywords: Nonlinear, Mathematical, Modeling, numerical and Computational

Introduction

The nonlinear equations form one of the most important and studied fields in mathematics because of their broad application in the fields of science, engineering, economics, and social sciences. Nonlinear equations depict non-proportional interactions between variables, in contrast to linear equations where changes in one variable do not always result in a commensurate change in the other. The inherent complexity of nonlinear equations gives them better models of both artificial and natural processes, but they are more difficult to understand and calculate. Explicit solutions to simple linear low-degree equations have traditionally been the primary focus of research. While linear and quadratic equations have simple solutions, cubic and quartic equations are a little trickier. The absence of closed-form solutions to general equations combining higher-degree polynomials and transcendental equations was, however, immediately apparent. No algebraic or universal solution exists for polynomial equations of degree five or above, as stated by the well-known Abel Ruffini theorem. When mathematicians recognized they needed to discover new approaches to solve nonlinear equations, they marked a turning point in their field.

Since its foundation, computational and applied mathematics has relied on the root-finding problem of polynomials, which now permeates many modern scientific fields. Applying a range of mathematical tools makes it straightforward to turn many engineering problems into non-linear functions, which can then be addressed using different numerical approaches. Analytical methods often fall short when confronted with such problems, thus we have to try out different iteration tactics to get a good estimate. Selecting a starting point estimate to execute the algorithm is the first and most important stage in any iteration approach. Two critical features of iteration schemes the rate and order of convergence are determined by the choice of that starting point. This is the starting point for each cycle's filtering process, which continues until the stopping condition is satisfied. In the fifteenth century, there was a conventional iterative system. Many academics expanded upon Newton's approach by delving further into iteration schemes, eventually leading to many versions that attained higher convergence orders. The iterative approaches used by many of these methods have multi-step designs, with predictor and corrector steps being commonplace.

Evaluating the function with higher-order derivatives increases the processing cost each iteration, which is the fundamental downside of multi-step iterative approaches. The inclusion of predictor and corrector stages, however, usually results in larger convergence orders for these approaches. Managing the two is difficult because of the apparent inverse link between computational cost and convergence rate. Recent years have seen mathematicians focus on the issue I just described, with the aim of developing iteration schemes to reduce processing cost each iteration and increase convergence rate using different mathematical techniques. By using a finite difference methodology to eliminate second derivatives, a sixth-order predictor-corrector variant of Halley's technique was transformed into a novel fifth-order method in 2007. In 2017, a new class of three-step optimal eighth-order approaches was established by using higher-order weight functions in the second and third sub-steps.

After that, they looked at how these approaches work, which rely on extraneous fixed points that don't exist. showcased two novel seventh-order and ninth-order root-finding algorithms, respectively, that draw on the predictor-corrector approach and the weight combination of midpoint with Simpson quadrature equations. Utilizing weight functions and the Newton interpolation approach, an optimal class of eighth-order algorithms in 2018. Afterwards, we established their use by fixing a slew of real-world problems in chemical engineering and suggested a slew of optimal, higher-level alternatives. Who recently developed an effective family of concurrent iterative algorithms gave a comprehensive dynamical analysis of the suggested methods. Some recent works dealing with non-linear equation systems, relevant domains, and applications are cited in. There has been a surge of interest in regular differential equations as of late. This model provides an approximation of the analytical solution for the free-loading x, y, and z variables; students may use it to attempt to estimate these variables. Models like SIR and SIRS are provided to elucidate this approach.

Literature Review

Amir Naseem (2023) [1] This paper aims to build a new root-finding technique by combining forward and finite-difference methods. An efficient algorithm with decreasing processing cost with each iteration and no need for derivatives is the target. The goal will be accomplished by combining forward and finite-difference techniques. Beside this, we clarify the root-finding strategy's convergence criteria and show that the proposed technique is convergent in the quintic order. To prove that our root-finding approach was both practical and legitimate, we took on several technical problems. Quantitative results comparing the created root-finding algorithm's performance to existing quintic-order methods in the literature confirmed the algorithm's robust performance. We use the newly discovered method to plot several novel and aesthetically beautiful polynomiographs for the graphical analysis. Afterwards, we compare and contrast these novel plots with previously developed quintic-order root-finding algorithms. Visual examination shows that compared to previous comparable approaches, the newly proposed root-finding methodology converges more strongly with the larger area.

M. A. Rehman (2022) [2] One common issue in engineering is finding solutions to non-linear equations. The use of non-linear functions makes it easier to reproduce the majority of the challenging engineering challenges. The influence of iterative algorithms on the evolution of computational solutions to these kinds of issues is now impossible to deny. The primary measures of an iterative algorithm's efficiency and performance are the computing cost per iteration and the convergence order. This means that a lower-order solution that requires more computing power will be more efficient, and vice versa. Having taken all of this into account, the primary objective of this research is to present a novel iterative approach to performance improvement that does not rely on derivatives. The renowned Householder's approach is enhanced with the forward- and finite-difference methods to produce this algorithm. Because of this, we have an efficient method without derivatives and with a low processing cost every iteration. Furthermore, we prove that the proposed approach is quartic-order convergent by analyzing its convergence criteria. Analyzing and solving nine test-examples allows us to statistically prove its correctness, validity, and efficiency. Cases like this also show how chemical and civil engineers face real-world problems.

Mário Basto (2017) [3] It is possible that the behavior of an iterative approach that is used to nonlinear equations is extremely sensitive to the beginning locations. The analysis of the basins of attraction in the complex plane C provides evidence for comparisons between the various iterative approaches. In most cases, however, information about the pace of convergence is not provided. The purpose of this work is to undertake a numerical comparison of three techniques that have the same structure. The BSC, Halley, and Euler-Chebyshev techniques are three examples of such a strategy. This comparison makes extensive use of examples of both algebraic and transcendental equations. The analysis considers the convergence rate as well as the basins of attraction. The number of iterations used to measure the pace of convergence is limited if an equation root is obtained within a given tolerance.

Isaac Azure (2019) [4] The convergence rates of five separate numerical approaches will be compared in this study. Methods such as Bisection, Newton Raphson, Regula Falsi, Secant, and Fixed-Point Iteration will be discussed. Using a gadget inspired by TI, one may manually solve a root-finding issue by creating and running a computational algorithm for each possible solution. The outcome of the computations showed that all methods converged to an exact root of 1.56155, however the Bisection method converged at the 14th iteration, Fixed Point Iterative Method converged at 7th iteration, Secant method converged at the 5th iteration and Regula Falsi and Newton Raphson methods converged at the 2nd iteration, suggesting that Newton Raphson and Regula Falsi methods are more efficient in computing the roots of a nonlinear quadratic equation.

Azizul Hasan (2016) [6] An introduction to the numerical study of several iterative approaches for solving non-linear equations is presented in this work. A wide variety of iterative approaches to solving algebraic and transcendental problems are illustrated by the various formulas. Using the bisection technique, the secant method, and the iterative approach developed by Newton, and comparing the outcomes of each of these methods. For the purpose of locating the root of the function for the interval the program known as MATLAB 2009a was utilized. All calculations have yielded the same numerical root-convergence rate. The Bisection method converges at iteration 47; following that, the Secant method converges at iteration 5 and the Newton method converges at iteration 4 to the precise root of 0.36042170296032 with an error level of 10-4. It was also found that the secant approach needed far less iterations than the Newton methodology. When evaluating performance, however, we must take into account not just the cost but also the pace of convergence. Then, after giving each of the three approaches some thought, the best results were produced by the Secant technique. Results from numerical experiments demonstrate that the secant method outperforms the others.

Nonlinear Equations in Mathematical Modeling

Within the framework of the nonlinear ordinary differential equation system, a number of distinct features are addressed. Regular differential equations have recently attracted a lot of attention. Students may use this model to try to estimate the free-loading x, y, and z variables, which is an approximation of the analytical answer. To clarify this method, we provide a number of models, such as SIR and SIRS. To get analytically approximate or approximative solutions to models, one uses the Homotopy perturbation method, one of the most important techniques ever invented. The nonlinear ordinary differential equation must be considered in this instance. The first proposal for a model based on ordinary differential equations was made by Perelson, Krischner, and De Boer in 1993. The x, y, and z phenomena form the basis of this concept. Even at a quick look, its model is noticeable. In more than one sense, this model was crucial to the development of the nonlinear. At this point, we update the equation using the nonlinear system's beginning and boundary values. Analysis of the nonlinear ordinary differential equation is our primary goal. In order to further our understanding of the system, we must analyze the numerical responses. One common criticism leveled at this model is how closely it resembles actual issues. Finally, the model's solution will be approximated in this research using the Homotopy Perturbation technique (HPM). In another section, we go into depth about a method for obtaining numerical solutions. The nonlinear system's ability to control the quantities of x, y, and z is an essential function.

Nomenclature

x Number of first compartment

y Number of second compartment

z Number of third compartment

Here s, d, a, β, ρ, δ, q and c all are constants

Mathematical modeling

The system nonlinear ordinary differential equation model:

$$\frac{dx}{dt} = s - dx + ax - \beta xz + \rho y \qquad (1)$$

$$\frac{dy}{dt} = \beta xz - \delta y - \rho y \qquad (2)$$

$$\frac{dz}{dt} = qy - cz \qquad (3)$$

In order to find the approximate solution of the above system, we need the following initial and boundary conditions:

x (0) =0, y (0) = 0, z (0) = 0 and

x (0) =32, y (0) = 20, z (0) = 3208.

Homotopy Perturbation Method (HPM)

In the fields of engineering sciences and applied sciences, the homotopy perturbation approach is used to solve a wide variety of nonlinear problems. In the diffusion equation, the nonlinear dynamical system, the Blasius equation, and a great number of differential equations, such as Burger's equations and Volterra's integra differential equations, this Homotopy perturbation approach is utilized. In Appendix A, we offer a practical method for obtaining an analytical or approximate solution to a wide range of issues that can be found in a number of professions. When it comes to solving non-linear differential equations, this approach is generally recognized and approved. When it comes to the implementation of non-linear differential equations, this is one of the straightforward and uncomplicated methods. Within this context, we will consider the parameter p to be a minor parameter. Utilizing the Homotopy perturbation approach, the solution to the system described above is as follows:

$$(1-p)\left(\frac{dx}{dt} - s + dx - ax\right) + p\left(\frac{dx}{dt} - s + dx - ax + \beta xz - \rho y\right) = 0 \qquad (4)$$

$$(1-p)\left(\frac{dy}{dt} + \delta y + \rho y\right) + p\left(\frac{dy}{dt} - \beta xz + \delta y + \rho y\right) = 0 \qquad (5)$$

$$(1-p)\left(\frac{dz}{dt} + cz\right) + p\left(\frac{dz}{dt} - qy + cz\right) = 0 \qquad (6)$$

Comparing the coefficient of p, we get

$$x_0 = \left(30 - s/d\right)e^{-dt} + \frac{s}{d} \qquad (7)$$

$$y_0 = 400e^{-(\delta+\rho)t} \tag{8}$$

$$z_0 = 600e^{-ct} \tag{9}$$

$$\frac{A(30-s/d)}{A-d}\left(e^{-At}-e^{-dt}\right)+\frac{s}{d}\left(e^{-At}-1\right)$$

$$+\frac{600\beta(30-s/d)}{A-c-d}\left(e^{-At}-e^{-(c+d)t}\right)+$$

$$\frac{600\beta(s/d)}{A-c}\left(e^{-At}-e^{-ct}\right)+\frac{400\rho}{A-\mu}\left(e^{-\mu t}-e^{-At}\right) \tag{10}$$

$$y_1 = 20e^{-Bt}+\frac{600\beta(30-s/d)}{B-c-d}\left(e^{-(c+d)t}-e^{-Bt}\right)$$

$$+\frac{600\beta(s/d)}{B-c}\left(e^{-ct}-e^{-Bt}\right)$$

$$z_1 = 3200e^{-ct}+\frac{400q}{c-\mu}\left(e^{-\mu t}+e^{-ct}\right) \tag{11}$$

Were,
A=d- a;
B= δ+ ρ;
μ= σ+ ρ.

The Homotopy perturbation method is gives the approximate analytical solution of the above system we consider as is

$$x(t)=\left(30-s/d\right)e^{-dt}+\frac{s}{d}+32e^{-At}+\frac{2A}{s}$$

$$\left(1-e^{-At}\right)+\frac{A(30-s/d)}{A-d}\left(e^{-At}-e^{-dt}\right)$$

$$+\frac{s}{d}\left(e^{-At}-1\right)+\frac{600\beta(30-s/d)}{A-c-d}\left(e^{-At}-e^{-(c+d)t}\right)$$

$$+\frac{600\beta(s/d)}{A-c}\left(e^{-At}-e^{-ct}\right)+\frac{400\rho}{A-\mu}\left(e^{-\mu t}-e^{-At}\right)$$

$$y(t)=400e^{-\mu t}+20e^{-Bt}+\frac{600\beta(30-s/d)}{B-c-d}$$

$$\left(e^{-(c+d)t}-e^{-Bt}\right)+\frac{600\beta(s/d)}{B-c}\left(e^{-ct}-e^{-Bt}\right)$$

$$z(t)=600e^{-ct}+3200e^{-ct}+\frac{400q}{c-\mu}\left(e^{-\mu t}+e^{-ct}\right)$$

Role of Computational Mathematics

Computational mathematics is a subfield of mathematics that focuses on the creation and use of mathematical algorithms, methods, and models for the purpose of resolving complicated problems in a variety of fields, including science, engineering, finance, and other academic disciplines. It is the process of applying mathematical principles and methods to the analysis and resolution of issues through the use of computers. In recent years, computational mathematics has gained prominence as an essential resource for cutting-edge scientific inquiry and technological advancement. Not only has it greatly accelerated scientific and technical progress, but it has also transformed several domains, such as climate modeling and financial analysis. Algorithms are an integral aspect of computational mathematics. An algorithm is a collection of instructions for completing a task. Techniques like the Newton-Raphson algorithm make it feasible to determine the mathematical function's roots. To carry out the process, a computer is used, and its primary function is to do the computations required to address the issue. From basic mathematical computations to intricate simulations, algorithms are effective for tackling a wide variety of issues. In computational mathematics, mathematical models play a crucial role. In order to examine and understand the behavior of a real-world system, researchers often utilize simplified representations, known as models. Weather patterns, economic systems, and biological processes are just a few examples of the complex systems that may be modelled. Scientists and engineers may study how these systems are behaving right now and predict what they will do next by utilizing models.

Applications of computational mathematics

In the field of scientific inquiry, computational mathematics is utilized widely for the purpose of modeling and simulating physical processes. Among the many uses of computer models are the forecasting of material behavior under various situations and the investigation of fluids (including air and water).

In engineering, computational mathematics is useful for optimizing and simulating the performance of products and systems. The design of complicated systems, like airplanes and automobiles, is one area that makes use of computer models. A variety of financial systems may be modeled and simulated with the help of computational mathematics. The values of derivatives like options and futures, for instance, are established by use of computer models. Similar models may also be used to simulate the financial markets.

The modeling and simulation of biological processes is one-way computational mathematics is used in medical research. Several fields use computational models, including the study of cellular, tissue, and organ activity, the creation of new medications and therapies, and many more.

Examples of computational mathematics

Weather forecasting: There are complicated computer models of the atmosphere of the Earth that are created via the application of computational mathematics. A number of environmental factors, including air and water, may be represented by this kind of model via the application of mathematical equations. Scientists may use these models to predict future weather and climatic trends.

Cryptography: Among the several applications of computational mathematics is the development of robust encryption protocols. To make data unintelligible to prying eyes, encryption methods use mathematical functions to scramble the data. To ensure the safety of sensitive data and online transactions, these algorithms must be used.

Among the many uses for financial models constructed using computational mathematics are the modeling of financial markets and the pricing of financial assets such as stocks and bonds. It is possible to predict the worth of financial instruments using models that mimic the behavior of financial markets using mathematical formulae.

Among computational mathematics' many applications are the optimization of systems and processes. For example, optimization techniques are used to enhance the design of complicated systems, such as aero planes. In order to discover the best answer to a problem, such as a design that optimizes lift and reduces drag, these algorithms employ mathematical equations.

Computational Mathematics in Solving Complex Problems

The area of computational mathematics is an extremely important tool for resolving difficult issues that emerge in a wide variety of academic disciplines, including but not limited to the domains of science and engineering, economics, and healthcare. Within this multidisciplinary domain, one may find first-rate tools for simulating and analyzing complex systems. These tools are made possible by combining computer approaches with mathematical ideas. This study will focus on the practical applications of computational mathematics to real-world challenges while discussing its underlying principles and approaches. Computational mathematics focuses on solving mathematical problems using computer computing and primarily includes the development and use of numerical methods and algorithms. The analytical solution to these issues is sometimes very challenging, if not impossible, due to the complexity of the mathematical models and equations involved. By using a framework developed in computational mathematics, we may estimate solutions and get valuable insights from these intricate systems.

The use of computational mathematics with scientific inquiry is a crucial application of the field. Scientists may examine how natural systems behave by replicating physical phenomena using computer models. Every scientific discipline finds this to be true, including astronomy, biology, chemistry, and physics. Computing mathematics has several applications, such as studying the behavior of quantum systems, simulating the birth of galaxies, and fluid flow dynamics, to name a few. Using computer simulations, researchers may get a better understanding of complicated systems, generate hypotheses, and direct the design of investigations. Engineering relies heavily on computational mathematics for system optimization and design. The use of numerical approaches allows engineers to model and study a wide variety of products, including buildings, vehicles, and electrical circuits. Mathematical computations allow engineers to explore many design options, see how various factors influence the end result, and locate the optimal balance between safety, efficiency, and cost. Here we see how Computational Fluid Dynamics (CFD) models may be used to develop aerodynamic and fuel-efficient vehicles by simulating the flow of air around vehicles and planes.

Computational mathematics has shown to be very useful in the financial industry for a number of applications, including risk analysis, portfolio optimization, and option pricing. When it comes to managing risks, evaluating investment plans, and monitoring market trends, financial organizations rely on computer models. One method for determining the worth of financial derivatives using computers is the Monte Carlo simulation. This method generates a plethora of potential future scenarios in order to arrive at an estimate. As a result, they may use probability distributions to make educated selections after considering the pros and cons of various investment options. The medical field and healthcare are likewise profoundly impacted by computational mathematics. Among the many possible applications of this software platform are the simulation of biological system behavior, the analysis of medical imaging data, and the modeling of infectious disease transmission. Computer models facilitate the exploration and optimization of possible medication candidates in the drug development process. Compared to the old-fashioned method of trial and error, this may save both time and money. Through the analysis of patient data, computational mathematics enables personalized medicine by developing models for diagnostic, therapeutic, and prognosis prediction.

Data analysis and machine learning also make extensive use of computational mathematics. Finding useful patterns and insights in the massive volumes of data produced by many businesses requires the use of computational techniques. Computational tools such as clustering, classification, regression, and anomaly detection algorithms are commonplace in data analysis. When it comes to training models, generating predictions, and learning from data, machine learning algorithms-the backbone of AI-rely substantially on computational mathematics. Improving computer hardware and software goes hand in hand with expanding computational mathematics. Computational mathematics has expanded in breadth and depth with the availability of powerful computing resources and the improvement of algorithms. Computations are now faster and more scalable because to cloud computing, distributed systems, and parallel computing.

Because of this, ever-larger and more intricate simulations can now be run. Computational mathematics has an essential and particularly important role in mathematics when dealing with complicated situations. Complex systems that were previously intractable analytically may now be easily modeled, optimized, and analyzed. This is made possible by using mathematical ideas and computer technology. Applied and academic computational mathematics equips people to solve practical issues, base judgments on data, and propel innovation in fields as varied as engineering, medicine, economics, and science. As the complexity of issues continues to rise, computational mathematics may play a significant role in determining the direction of future studies, innovations, and solutions. Since processing power is only increasing, this prospect may come to fruition.

Conclusion

The convergence rate of Bisection is too slow to be helpful for systems of equations, even when convergence is certain; in contrast, Newton's Rhapson approach works well. This is something I had previously recognized. Using the bisection and Newton's-Raphson techniques, one may execute important numerical tasks including root approximation for nonlinear equations and numerical zero computation. Get to know the features, advantages, and disadvantages of each strategy to help you pick the best one for any particular job. Additionally, researchers are focusing on hybrid strategies and adjustments to boost convergence rates and resilience while dealing with root-finding challenges. The predictor and corrector phases are really part of larger iterative processes used by many of these systems. Mathematical models, algorithms, and methods are the focus of computational mathematics, a subfield of mathematics that aims to solve complicated issues in many academic fields (e.g., science, engineering, finance, etc.). Data analysis often makes use of computational tools such algorithms for grouping, classification, regression, and anomaly detection. Computational mathematics has several applications in engineering, including product and system performance optimization and simulation. One field that takes use of computer models is the design of complex systems, such as aircraft and vehicles.

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