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Retraction

Retracted: Numerical Analysis of Two Kinds of Nonlinear Differential Equations Based on Computer Energy Simulation

Wireless Communications and Mobile Computing

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] F. Li, “Numerical Analysis of Two Kinds of Nonlinear Differential Equations Based on Computer Energy Simulation,” *Wireless Communications and Mobile Computing*, vol. 2022, Article ID 1733367, 6 pages, 2022.

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Research Article

Numerical Analysis of Two Kinds of Nonlinear Differential Equations Based on Computer Energy Simulation

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In order to solve some shortcomings, such as the traditional integer order calculus theoretical model is in good agreement with the numerical experimental results, the fractional order calculus model in many fields such as modern engineering calculation is proposed, which has been paid more attention and applied than the integer order calculus model. In such problems, nonlinear fractional differential equations sometimes bring us many unexpected surprises, so as to get unexpected conclusions about the description of the problem. The experiment shows that when the time $t = 0.5$, the error between them is 0.0305, and the error is slightly larger. In this case, we can reduce the overall error by adding a new term of the decomposition sequence, and the approximate analytical solution can be closer to the exact solution, which verifies the effectiveness of the experiment.

1. Introduction

As the problems we study become more and more complex, compared with the traditional calculus with integer order, the specific problems of many disciplines can be better described and solved [1]. At the same time, some shortcomings such as the traditional integer order calculus theoretical model is consistent with the numerical experimental results, and the effect is unsatisfactory have also been well solved. Therefore, in many fields such as modern engineering calculation, the fractional order calculus model has been paid more attention and applied than the integer order calculus model, as shown in Figure 1. However, for many complex problems, the linear fractional differential equation cannot give a better model to describe. In such problems, the nonlinear fractional differential equation sometimes brings us many unexpected surprises, so as to get the unexpected conclusion of the problem description [2]. Although nonlinear fractional differential equations well describe many specific problems in practical applications, how to solve these nonlinear fractional differential equations has become a difficult practical problem in front of people. In this paper, the numerical solution of nonlinear fractional differential equations is mainly studied by the difference method, and the corresponding theoretical proof and numerical example are given.

2. Literature Review

Professor Mandelbrot ill from Yale University once put forward the fact of fractal dimension in the 1970s, which widely exists in many fields of nature and science and technology [3]. Since then, Hernández-Vázquez and others have found that fractional operator theory, as the basis of fractal, has achieved rapid development in international academia and opened up a broad development space for fractional operator theory and its application [4]. Chen and others found that, especially in recent decades, with the deepening of people's understanding of things, many scholars found that the fractional derivative as a quasidifferential operator is nonlocal [5]. Thus, it describes the dynamic transmission process of anomalous diffusion and the process with memory and genetic characteristics, gives a method with great application value, and can describe many natural phenomena more accurately than the integer order differential model. Gu and others believe that in addition to the wide application of fractal, fractional differential equations developed from fractional calculus theory are also widely used in many fields

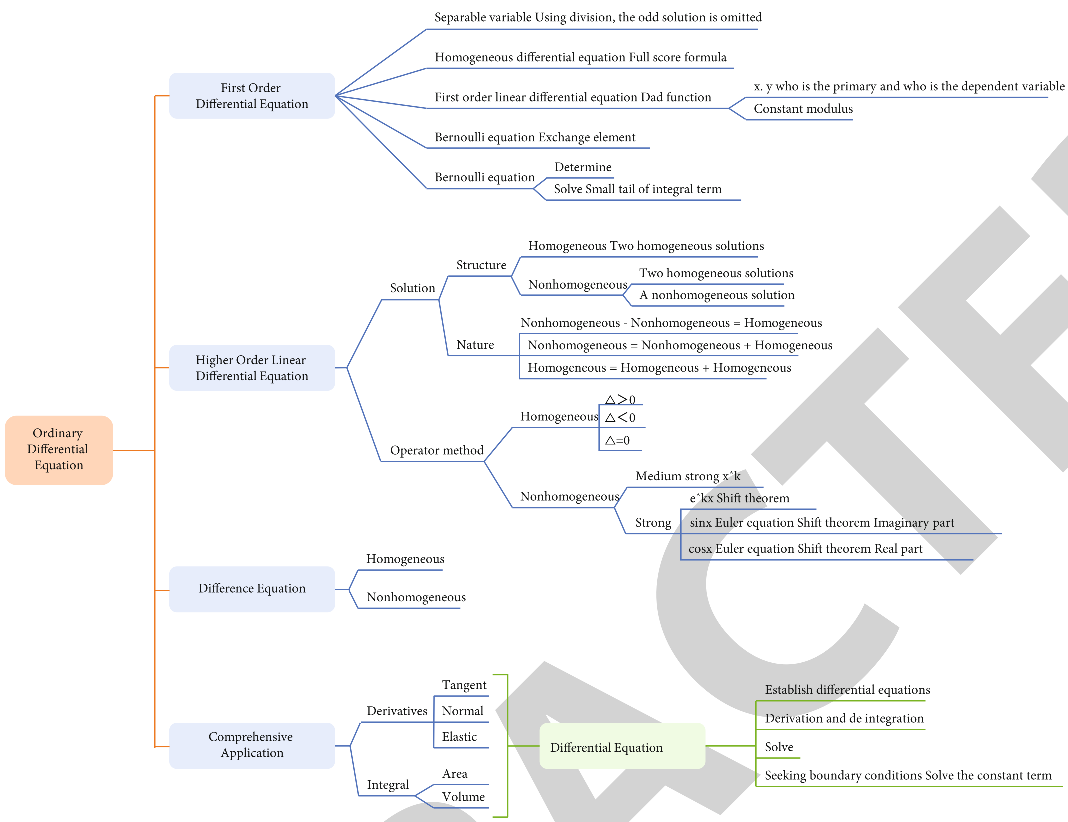

Figure 1: Numerical analysis of nonlinear differential equations.

such as physics, biology, engineering, finance, and even random walk [6]. Ramos and others found that for the diffusion equation with fractional order, the abnormal characteristic problems often appear in many problems can be well explained by it, such as abnormal transport process, gating dynamics of ion channels in some proteins, and application in cancer treatment [7]. Wang and others believe that fractional derivative has also been greatly applied and developed in delay differential equations. It has been widely used in many fields such as automatic control, ecology and power engineering, and has achieved some gratifying results [8]. Guo and others believe that, for example, in the population growth model, in the ordinary differential equation with integer order, the general solution of the first-order differential equation with simple form can be obtained directly. In addition, there are linear equations and equations with separable variables and equations that can be transformed into these two equations by some special methods, and the number of such equations is very small [9]. Kuznetsov and others found that the number of equations that can be solved by superposition principle in higher-order equations is also very small. In addition, most other equations cannot get their analytical solutions. However, compared with integer order differential equations, fractional order differential equations are more complex, and the number of equations that can obtain analytical solutions is less [10]. Olutimo and others found that in recent ten years, the application fields of fractional calculus theory have become very extensive, including material memory, mechanics, seismic analysis, electronic circuit, electrolytic chemistry, fractal theory, and many other fields. Since the analytical solutions of fractional differential equations are mostly composed of extremely complex series or special forms of functions, it also brings many difficulties to approximate calculation. Therefore, it is particularly important to study the numerical solutions of fractional differential equations [11]. Liu and others believe that the theoretical analysis of the numerical solution of fractional differential equations is also regarded as a very difficult thing, especially the nonlinear fractional differential equations. The solution of nonlinear differential equations is a problem often encountered in practical engineering applications. It widely appears in various fields of engineering technology and mathematical physics. Many practical problems can be described by nonlinear differential equations; so, the solution of nonlinear differential equations becomes more and more important [12]. Arora et al. found that for some special nonlinear differential equations, we can give their analytical solutions, but the methods used in the process of finding the analytical solutions are usually complex. For most differential equations, we can only give theoretical analysis such as the existence of solutions, but we still cannot get the form of solutions accurately [13]. Therefore, most nonlinear differential equations cannot give the form of solution by the analytical method, but the real and accurate quantitative data are often urgently needed by scientists and engineers. Therefore, we must rely on numerical methods to calculate and solve, which is also the most important significance of numerical calculation. Therefore, the research on numerical methods of nonlinear equations (systems) has its wide practical application background and development space and has become a major subject attracting many scholars and challenging at the same time.

3. Method

In the analysis and design of automatic control system, Laplace transform is a mathematical tool to solve linear differential equations. Laplace transform is abbreviated as Laplace transform [14]. It is a kind of function transformation. A differential equation becomes an algebraic equation after Laplace transformation, and the initial conditions are introduced at the same time of transformation, which avoids the trouble of solving the integral constant by the classical method. Therefore, this method can simplify the process of operation and solving the differential equation.

In the control of computer energy, feedback control is the most common form of control system. The typical structure of the feedback control system can be shown in Figure 2. In the figure, u represents the given input signal, B is the feedback signal, E is the error between the given signal and the feedback signal, N is the interference input signal, and Y is the output. Based on the needs of control system analysis, some concepts of transfer function are introduced below [15].

3.1. System Open Loop Transfer Function. The open-loop transfer function of the system is the main mathematical model of the control system designed by the root locus method. In Figure 2, if the output end of the feedback link $H(s)$ is disconnected, the product $G(s)G$ of the forward channel transfer function and the feedback channel transfer function, $(s)H(s)$, is called the open-loop transfer function of the system, which is equivalent to $B(s)/E(s)$.

3.2. Closed Loop Transfer Function of System under Given Signal. When $N = 0$ in Figure 2, the transfer function of output y to given input u is as shown in equation (1):

$$\Phi(s) = \frac{Y(s)}{U(s)} = \frac{G_1(s)G_2(s)}{1 + G_1(s)G_2(s)H(s)}, \quad (1)$$

$\Phi(s)$ is the closed-loop transfer function of the system under a given action. It is often used in time domain performance analysis of systems.

Discrete control system is relative to continuous time system [16]. All signals in a continuous time system are continuous functions of time variables; so, it is called a continuous time system or continuous system for short. The discrete-time system refers to that one or several signals in the system that are a series of pulses or numbers; that is, these signals are discrete in time; so, it is called discrete-time system. When the discrete signal in the discrete system is in the form of pulse sequence, it is called sampling control system. If the discrete signal in the discrete system is in the form of digital sequence, it is called digital control system or computer control system [17].

Figure 3 shows the most widely used discrete control system in HVAC-error sampling control system. In the figure, the sampling switch is between deviation signals

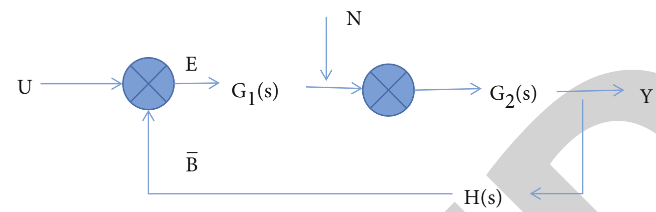

Figure 2: Block diagram of feedback control system.

$e(t)$ and $e*(t)$ and between controller output signals $u(t)$ and $u*(t)$. The pulse amplitude of the sampling instantaneous is equal to the amplitude of the corresponding sampling instantaneous signal, and the sampling duration τ tends to zero.

$G_c(s)$ is the transfer function of the controller, $G_h(s)$ is the transfer function of the holder, $G_p(s)$ is the transfer function of the controlled object, and $H(s)$ is the transfer function of the feedback element. It can be seen from Figure 3 that some signals in the system are not continuous functions of time; so, the sampling control system is a discrete (time) system.

The study of continuous systems needs the help of Laplace transform and transfer function, while the study of discrete systems usually adopts Z transform and impulse transfer function. The relationship between Z-transform method and linear steady discrete system is just like that between Laplace transform and linear steady continuous system. Through Z-transform, the concepts of transfer function and root locus (which is a powerful tool for control system analysis) can be applied to discrete control systems.

The mathematical model of the control system is a mathematical expression describing the static and dynamic relationship between the system input, output variables and internal variables [18]. Computer simulation and aided design of control system are based on the mathematical model of control system. For the analysis and design of various control systems by means of simulation, the corresponding system mathematical model needs to be established first, and then the system mathematical model needs to be transformed into a simulation model suitable for computer analysis and calculation, that is, the numerical algorithm model. On this basis, the analysis and design of the dynamic and static characteristics of the system can be realized through the solution and analysis of the mathematical model. There are many forms of mathematical models, such as algebraic equations, static structure diagrams, and static relationship tables that describe the static characteristics of the system; Differential equation, difference equation, transfer function, state equation, dynamic structure diagram, and dynamic relationship table are used to describe the dynamic characteristics of the system. An automatic control system is composed of many components (or links). Usually, they are not classified according to function or structure but divided into different links according to their dynamic characteristics. This is because the progress of the regulation process only depends on the dynamic characteristics of each link and has nothing to do with the specific structure or function of each link. Therefore, we generally divide the links

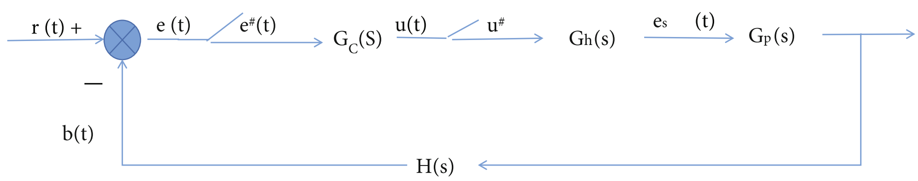

Figure 3: Error sampling closed loop control system.

constituting the control system into several basic links (often referred to as typical links) for analysis. In the field of HVAC control, the common typical links are as follows: inertia link, proportional link, differential link, and pure lag link.

Inertia link is also called aperiodic link or single [19] capacity link. Its differential equation form is shown in formula (2):

$$T_c \frac{dy(t)}{dt} + y(t) = kx(t), \tag{2}$$

where T_c is the time constant of inertia link, and $k-$ is the transfer coefficient of inertia link or amplification coefficient.

In real life, the ideal proportional link does not exist, but when the time constant of some components is so small that the time constant relative to the control object can be ignored. In this case, these elements can be approximately regarded as proportional links. When we study the building automatic control system, we often encounter some components with small inertia, such as pneumatic diaphragm valve and electric heater, which are often regarded as proportional links [10, 20].

4. Experiment and Discussion

The order of fractional derivative is usually real valued constant or complex valued constant, but it can also be a function of time or space variables [21, 22]. In recent years, due to the increasing complexity of the problems studied, variable fractional derivatives that change with time and space appear in some models. Therefore, variable fractional derivatives have begun to appear in some academic monographs and articles. At the same time, they are also widely used as models to describe physical or chemical phenomena in some fields. In this paragraph, an explicit difference scheme will be given for this kind of nonlinear variable fractional diffusion equation, and the corresponding theoretical proof of stability and convergence will be given. Then, the numerical solution will be obtained through numerical examples, and then the effectiveness of the algorithm will be further verified by comparing the relative error between the numerical solution and the exact solution [23, 24]. When considering the nonlinear variable order fractional diffusion equation in the following form, see equation (3):

$$\begin{cases} \dfrac{\partial u}{\partial t} = B(x,t)_x R^{\alpha(x,t)} u(x,t) + f(u,x,t), \\ x_a < x < x_b, 0 < t < T, \\ u(x,0) = u_0(x), x_a < x < x_b, \\ u(x_a,t) = u_a(t) = 0, u(x_b,t) = u_b(t) = 0, 0 < t < T, \end{cases} \tag{3}$$

Table 1: Comparison of calculation results, exact solutions, and errors of Adomian splitting method at time $t = 0.3$.

X	Approximate analytical solution	Exact solution	Error
0	0.0055	0	0.0055
0.1	0.1036	0.098	0.0056
0.2	0.18	0.1743	0.0055
0.3	0.2346	0.2288	0.0056
0.4	0.2672	0.2615	0.0055
0.5	0.2781	0.2724	0.0055
0.6	0.2672	0.2615	0.0055
0.7	0.2345	0.2288	0.0055
0.8	0.17	0.1743	0.0055
0.9	0.1036	0.0985	0.0055
1	0.0055	0	0.0055

where $1 < \underline{a} \le a(x,t) \le a < 2$, $B(x,t) > 0$, and $f(u,x,t)$ satisfy the Lipschitz condition; that is, there is a constant L, so that see formula (4):

$$|f(u_1,x,t) - f(u_2,x,t)| \le L|u_1 - u_2|. \tag{4}$$

This makes the solution of the nonlinear variable order fractional diffusion equation exist and unique, as shown in Table 1 and Figure 4.

As can be seen from Figure 4 and Table 1 above, when $t = 0.3$, the numerical solution calculated by the Adomian splitting method is very consistent with the exact solution. The Adomian splitting method converges very fast and can provide high-precision approximate solution for the equation without discretization, as shown in Table 2 [25, 26].

As can be seen from Table 2 above, the smaller the time t is, the closer the approximate analytical solution calculated by the Adomian splitting method is to the exact solution, and the smaller the error is; when time $t = 0.5$, the error between them is 0.0305, and the error is slightly larger. In this case, adding a new term of decomposition sequence can make the overall error very small, and the approximate analytical solution can be closer to the exact solution, as shown in Figure 5.

The numerical solution and approximate analysis of two kinds of fractional differential equations are discussed. The first kind of equation is time fractional telegraph equation. Through numerical examples, it is found that the Adomian splitting method is an effective method to solve fractional differential equations, and this method has fast convergence speed,

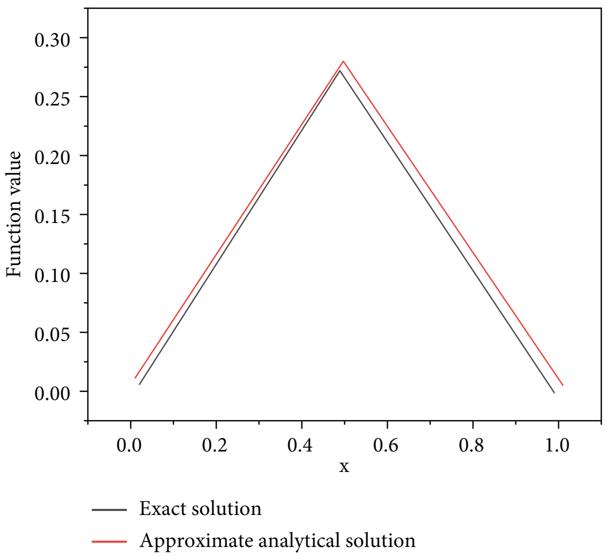

FIGURE 4: Approximate analytical solution and exact solution calculated by Adomian splitting method at $t = 0.3$.

TABLE 2: Approximate analytical solutions, exact solutions, and error comparison corresponding to different times when $x = 0.5$.

t	Approximate analytical solution	Exact solution	Error
0.01	0.25	0.25	0
0.05	0.2506	0.2506	0
0.07	0.2512	0.2511	0.0001
0.08	0.2516	0.2514	0.0001
0.09	0.2522	0.252	0.0001
0.1	0.2526	0.2524	0.0002
0.2	0.2615	0.26	0.0015
0.3	0.2781	0.2724	0.0056
0.4	0.3044	0.28	0.0144
0.5	0.342	0.3124	0.0304

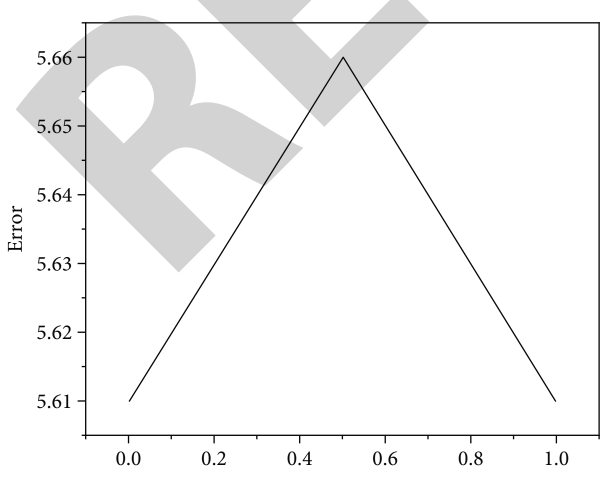

FIGURE 5: Error diagram between the exact solution at time $t = 0.3$ and the approximate analytical solution calculated by the Adomian iterative method.

For the equation, high-precision approximate solution can be provided without discretization, and the overall error can be reduced by adding new terms of decomposition sequence. In this paper, an implicit difference scheme is proposed, and the stability and convergence of the scheme are proved. The second kind of equation is a generalized space-time fractional convection diffusion equation; that is, the space-time fractional convection diffusion equation is extended. Firstly, the implicit difference scheme is constructed, and the stability and convergence of the scheme are proved. Secondly, the approximate analytical solution of the equation is discussed by using the variational iterative method. The variational iterative method is an integral iterative scheme, which is easy to calculate and the calculation result is accurate [27].

5. Conclusion

Nonlinear fractional partial differential equations can well describe many specific problems in practical applications in many fields, but the solution of analytical solutions of nonlinear fractional partial differential equations has always been a very difficult problem. Therefore, how to solve the numerical solutions of these nonlinear fractional differential equations has become a difficult practical problem in front of people. Firstly, this paper discusses the numerical method of nonlinear time-space fractional convection diffusion equation. By approximating the space term and time term of the equation, the difference scheme of nonlinear time-space fractional convection diffusion equation is derived, and the corresponding theoretical analysis of stability and convergence is given. Finally, the numerical solution is obtained by solving the numerical example with MATLAB programming. The effectiveness of the difference scheme is further verified by the comparison between the numerical solution and the exact solution and the analysis of the relative error. Secondly, the numerical method of nonlinear variable fractional diffusion equation is discussed. Since the variable fractional derivative varying with time and space is extended from the definition of Riesz fractional derivative in the general sense, the method similar to the traditional Riesz fractional derivative is used for discretization, and the difference scheme of nonlinear variable fractional diffusion equation is given. Finally, a numerical example is given. The numerical solution is solved by MATLAB programming, and the method is effective after comparing the numerical solution with its analytical solution and analyzing the relative error. The numerical solution of nonlinear fractional differential equations is developing rapidly, and there is still a lot of important work to be done. Combined with the research process of this paper, this paper puts forward a problem that can be further studied: the calculations in this paper are calculated with fixed steps. If the principle of short memory or the idea of combining multiple methods is adopted, it is expected to reduce the workload of calculation and achieve better results.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that he/she has no conflicts of interest.

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