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APPROXIMATE SOLUTION FOR BURGER'S-FISHER EQUATION BY VARIATIONAL ITERATION TRANSFORM METHOD

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Abstract

Nonlinear partial differential equations represent the most important phenomena occurring in the world and are encountered in various fields of science. Generalized Burger's-Fisher equation is very important for describing different mechanisms. Burger's-Fisher equation arises in the field of applied mathematics and physics applications. This equation shows a prototypical model for describing the interaction between the reaction mechanisms, convection effect, and diffusion transport. In this paper, variational iteration transform method that combines Laplace transform and the variational iteration method, which used to obtain approximate analytical solutions of Burger's - Fisher equation. Comparison of the results obtained by the present method with the exact solution and other existing methods reveals the accuracy and fast convergence of the proposed method.

1. Introduction

Most of the problems in engineering and science are modeled by differential equations. Differential equations describe exchange of energy, information, matter, or any other quantities; often as they vary in time and space. These equations arise in various scientific fields such as the gas dynamics, traffic flow, and in applied mathematics and physics applications.

A compelling strategy is required to break down the scientific model which gives arrangements fitting in with physical reality. The nonlinear models of genuine issues are still exceptionally hard to unravel either numerically or hypothetically, more presumptions must be made pointlessly to make nonlinear models feasible. As of late, much consideration dedicated to the look for better and more productive arrangement strategies for deciding an answer, rough or correct, systematic or numerical, to nonlinear models [1–5]. Finding precise or estimated arrangements of these nonlinear conditions is intriguing and critical.

Many methods have been developed for providing approximate solutions of NPDEs. Some of these methods include pseudo spectral method [6], spectral collocation method [7], Adomian decomposition method (ADM) [8–10], homotopy perturbation method (HPM) [11–13], the differential transform method (DTM) [14-16] and variational iteration method (VIM) [17-18]. One of these approximate methods which have received a great deal of attention is the (VIM). The VIM is first proposed by his paper [19] in which the technique implemented on several nonlinear ordinary and partial differential equations [20–23].

The variational iteration transform method (VITM) [24] that combines Laplace transform and Obtaining approximate and exact solutions of linear and non-linear differential equations by using the variational iteration method. Applying the VITM in this paper is mainly used to get the approximate solutions of the generalized nonlinear Burger's-Fisher equation that put the interaction between reaction mechanisms, convection effects and diffusion transports [23]. The numerical results are compared with the exact solutions and that obtained previously by the VIM [25].

2. The Generalized Burger's-Fisher Equations

Consider the generalized Burger's-Fisher equation:

$$\frac{\partial u}{\partial t}+\alpha u^{\sigma}\frac{\partial u}{\partial x}-\frac{\partial^2 y}{\partial x^2}=\beta u(1-u^{\sigma}),0\le x\le 1,t\ge 0 \quad (1)$$

With initial condition

$$u(x,0)=\left(\frac{1}{2}+\frac{1}{2}\tanh\left(\frac{-\alpha\sigma}{2(\sigma+1)}\right)\right)^{\frac{1}{\sigma}}, \quad (2)$$

and boundary conditions

$u(0,t) = \left(\frac{1}{2}+\frac{1}{2}\tanh\left[\frac{-\alpha\sigma}{2(\sigma+1)}\left(\left(\frac{\alpha}{\sigma+1}+\frac{\beta(\sigma+1)}{\alpha}\right)t\right)\right]\right)^{\frac{1}{\sigma}},\ \ t \geq 0$ (3)

$u(1,t) = \left(\frac{1}{2}+\frac{1}{2}\tanh\left[\frac{-\alpha\sigma}{2(\sigma+1)}\left(1-\left(\frac{\alpha}{\sigma+1}+\frac{\beta(\sigma+1)}{\alpha}\right)t\right]\right)^{\frac{1}{\sigma}}, t \geq 0$ (4)

The exact solution of Eq. (1) is

$u(x,t) = \left(\frac{1}{2}+\frac{1}{2}\tanh\left[\frac{-\alpha\sigma}{2(\sigma+1)}\left(x-\left(\frac{\alpha}{\sigma+1}+\frac{\beta(\sigma+1)}{\alpha}\right)t\right)\right]\right)^{\frac{1}{\sigma}}$ (5)

where α, β *and* σ are constants, Generalized Burger's equation will be obtained when $\beta = 0$.

3. Variational Iteration Transform Method (VITM):

The basic idea of this method can be illustrated by considering the equation of a general nonlinear non-homogeneous partial differential with initial conditions as follow

$\mathfrak{D}u(x,t) + \mathcal{R}u(x,t) + \aleph u(x,t) = g(x,t)$ (6)

$u(x,0) = h(x), u_t(x,0) = f(x)$

where $\mathfrak{D}$ is the second order linear differential operator $\mathfrak{D} = \frac{\partial^2}{\partial t^2}$, $\mathcal{R}$ is linear differential operator of less order than $\mathfrak{D}$, $\aleph$ represent the general nonlinear differential operator and g(x,t) is the source term. Taking Laplace Transform on both sides of Eq.(6)

$\mathrm{L}[\mathfrak{D}\mathrm{u}(\mathrm{x},\mathrm{t})] + \mathrm{L}[\mathcal{R}\mathrm{u}(\mathrm{x},\mathrm{t})] + \mathrm{L}[\aleph\mathrm{u}(\mathrm{x},\mathrm{t})] = \mathrm{L}[\mathrm{g}(\mathrm{x},\mathrm{t})]$ (7)

$s^2\mathrm{L}[\mathrm{u}(\mathrm{x},\mathrm{t})] - su(x,0) - u_t(x,0) + L[\mathcal{R}u(x,t)] + L[\aleph u(x,t)] = L[g(x,t)]$ (8)

Taking Inverse Laplace transform

$u(x,t) = f(x) + th(x) + \frac{1}{s^2}L^{-1}[L(g(x,t))] - \frac{1}{s^2}L^{-1}[L(\mathcal{R}(x,t))] - \frac{1}{s^2}L^{-1}[L\aleph u(x,t)]$ (9)

Derivative by $\frac{\partial}{\partial t}$ both sides of Eq.(9)

$\mathrm{u}_t(x,t) = h(x) + \frac{\partial}{\partial t}L^{-1}\left(\frac{1}{s^2}L\{g(x,t)\}\right) - \frac{\partial}{\partial t}L^{-1}\left(\frac{1}{s^2}L\{\mathcal{R}u(x,t)\}\right) - \frac{\partial}{\partial t}L^{-1}\left(\frac{1}{s^2}L\{\aleph u(x,t)\}\right)$ (10)

By the correction function of the irrational method

$\mathrm{u}_{n+1}(x,t) = u_n(x,t) - \int_0^t((u_n)_\xi(x,\xi) + \frac{\partial}{\partial \xi}(L^{-1}\left(\frac{1}{s^2}L\{\mathcal{R}u_n(x,\xi)\} + L^{-1}\left(\frac{1}{s^2}L\{\aleph u_n(x,\xi)\}\right) - L^{-1}\left(\frac{1}{s^2}L\{g(x,\xi)\}\right) - h(x)\right)d\xi$ (11)

Finally, the solution *u*(*x*,*t*) is given by

$u(x,t) = \lim_{n\to\infty} u_n(x,t)$

4. Numerical Results

In this section we illustrate the ability and simplicity of the presented method for solving the nonlinear Burger's-Fisher equation. Two cases will be studied: the first case is when $\alpha = \beta = 0.01$ and $\sigma = 1$ in Eq. (1), whereas the second case is when $\alpha = \beta = 0.001$ and $\sigma = 1$, for various values of x and t.

Example **:**

Suppose the equation of generalized Burger's-Fisher:

$\frac{\partial u}{\partial t} + \alpha u^\sigma\frac{\partial u}{\partial x} - \frac{\partial^2 y}{\partial x^2} = \beta u(1-u^\sigma), 0 \leq x \leq 1, t \geq 0$

With initial condition

$u(x,0) = \left(\frac{1}{2}+\frac{1}{2}\tanh\left(\frac{-\alpha\sigma}{2(\sigma+1)}\right)\right)^{\frac{1}{\sigma}}$

<u>Case 1</u>: when $\alpha = \beta = 0.01$ and $\sigma = 1$.

$u_t - u_{xx} + 0.01uu_x + 0.01u(u-1) = 0$ (12)

with initial condition

$u(x,0) = \frac{1}{2} - \frac{1}{2}\tanh\left(\frac{0.01}{4}x\right)$ (13)

Taking Laplace transform on both sides on Eq.12

$L[u_t] - L[u_{xx}] + 0.01L[uu_x] + 0.01L[u(u-1)] = 0$ (14)

This can be written as

$sLu(x,t) - u(x,0) - L[u_{xx}] + 0.01L[uu_x] + 0.01L[u(u-1)] = 0$ (15)

Substituting the initial condition in Eq.(15) we get

$sLu(x,t) - \frac{1}{2} - \frac{1}{2}\tanh(0.0025x) - L[u_{xx}] + 0.01L[uu_x] + 0.01L[u(u-1)] = 0$ (16)

$L[u(x,t)] = \frac{1}{2s} + \frac{1}{2s}\tanh(0.0025x) + \frac{1}{s}L[u_{xx}] - \frac{0.01}{s}L[uu_x] - \frac{0.01}{s}L[(u-1)]$ (17)

Take Inverse Laplace to Eq.(17) obtain:

$$u(x,t) = L^{-1}\left[\frac{1}{2s}\right] + L^{-1}\left[\frac{1}{2s}\tanh(0.0025x)\right] + L^{-1}\left(\frac{1}{s}L[u_{xx}]\right) - L^{-1}\left(\frac{0.01}{s}L[uu_x]\right) - L^{-1}\left(\frac{0.01}{s}L[(u-1)]\right) \quad (18)$$

$= \frac{1}{2} + \frac{1}{2}\tanh(0.0025x) + L^{-1}\left(\frac{1}{s}L[u_{xx}]\right) - L^{-1}\left(\frac{0.01}{s}L[uu_x]\right) - L^{-1}\left(\frac{0.01}{s}L[u(u-1)]\right)$ (19)

Derivative by $\frac{\partial}{\partial t}$ both sides of Eq.(19) we get

$u_t(x,t) = \frac{\partial}{\partial t}\left[\left(\frac{L}{s}[u_{xx}]\right) - L^{-1}\left(\frac{0.01}{s}L[u_{xx}]\right) - L^{-1}\left(\frac{0.01}{s}L[u(u-1)]\right)\right]$ (20)

$u_t(x,t) - \frac{\partial}{\partial t}\left[L^{-1}\left(\frac{L}{s}[u_{xx}]\right) - 0.01L^{-1}\left(\frac{L}{s}[u_{xx}]\right) - 0.01L^{-1}\left(\frac{L}{s}[u(u-1)]\right)\right] = 0$ (21)

Making the correction function yields

$u_{n+1}(x,t) = u_n(x,t) - \int_0^t\left((u_n)_\xi(x,\xi) - \frac{\partial}{\partial\xi}\left[\left(\frac{L}{s}[(u_n)_{xx}]\right) - 0.01L^{-1}\left(\frac{L}{s}[u_n(u_n)_x]\right) - 0.01L^{-1}\left(\frac{L}{s}[u_n(u_n-1)]\right)\right]\right)d\xi$ (22)

Now we use the initial condition

$u_0(x,t) = u(x,0) = \frac{1}{2}(1-\tanh(0.0025x))$ (23)

$u_1(x,t) = u_0(x,t) - \int_0^t\left((u_0)_\xi(x,\xi) - \frac{\partial}{\partial\xi}\left[L^{-1}\left(\frac{L}{s}[(u_0)_{xx}]\right) - 0.01L^{-1}\left(\frac{L}{s}[u_0(u_0)_x]\right) - 0.01L^{-1}\left(\frac{L}{s}[u_0(u_0-1)]\right)\right]\right)d\xi$ (24)

$u_1(x,t) = \frac{1}{2} - \frac{1}{2}\tanh(0.0025x) + \int_0^t(\frac{\partial}{\partial\xi}\left[L^{-1}\left(\frac{L}{s}\left[\left(\frac{1}{2} - \tanh(0.0025x)\right)_{xx}\right]\right) - 0.01L^{-1}\left(\frac{L}{s}\left[\left(\frac{1}{2} - \tanh(0.0025x)\left(\frac{1}{2}-\frac{1}{2}\tanh(0.0025x)\right)_x\right]\right) - 0.01L^{-1}\left(\frac{L}{s}\left[\left(\frac{1}{2}-\frac{1}{2}\tanh(0.0025x)\right)\left(-\frac{1}{2} - \frac{1}{2}\tanh(0.0025x)\right)\right]\right)\right]\right)d\xi$ (25)

$$u_1(x,t) = \frac{1}{2} - \frac{1}{2}\tanh(0.0025x) + \int_0^t \Big(\frac{\partial}{\partial \xi}\Big[L^{-1}\Big(\frac{(0.0025)^2}{s}\Big(\Big[\frac{s^2-(0.0025)^2}{s}\Big]^2\Big(\frac{0.0025}{s^2-(0.0025)^2} \times \frac{s^2-(0.0025)^2}{s}\Big)\Big) - 0.01L^{-1}\Big[\Big(\frac{-0.0025}{4s}\Big) \times \Big(\frac{s^2-(0.0025)^2}{s}\Big)^2 + \frac{0.0025}{4s}\Big[\Big(\Big(\frac{0.0025}{s^2-(0.0025)^2}\Big) \times \Big(\frac{s^2-(0.0025)^2}{s}\Big)\Big) \times \Big(\frac{s^2-(0.0025)^2}{s}\Big)^2\Big]\Big] - 0.01L^{-1}\Big(\frac{1}{4s^2} + \frac{4}{s}\Big(\frac{0.0025}{s^2-(0.0025)^2} \times \frac{s^2-(0.0025)^2}{s}\Big)^2\Big)\Big]\Big) d\xi \qquad (26)$$

$$= \frac{1}{2} - \frac{1}{2}\tanh(0.0025x) + \int_0^t \Big(\frac{\partial}{\partial \xi}\Big[\Big(-2(0.0025)^5 + \frac{(0.0025)^7}{2}\xi^2\Big) - \frac{0.01(0.0025)}{4}\Big[2(0.0025)^2 - \frac{(0.0025)^4}{2}\xi^2 + 2(0.0025)^3\xi - \frac{(0.0025)^5}{3!}\xi^3\Big] - 0.01\Big(\frac{\xi}{4} + 2(0.0025)^2\xi^2\Big)\Big]\Big) d\xi \qquad (27)$$

$$u_1(x,t) = \frac{1}{2} - \frac{1}{2}\tanh(0.0025x) + \frac{0.01(0.0025)^6}{24}t^3 + \Big(\frac{(0.0025)^7}{2} + \frac{0.01(0.0025)^5}{8} + 2(0.01(0.0025)^2)\Big)t^2 - 0.01\Big(\frac{(0.0025)^4}{2} + \frac{1}{4} + 4(0.0025)^2\Big)t \qquad (28)$$

Therefore, the approximate solution:

$$u(x,t) \simeq u_1(x,t) = \frac{1}{2} - \frac{1}{2}\tanh(0.0025x) + \frac{0.01(0.0025)^6}{24}t^3 + \Big(\frac{(0.0025)^7}{2} + \frac{0.01(0.0025)^5}{8} + 2(0.01(0.0025)^2)\Big)t^2 - 0.01\Big(\frac{(0.0025)^4}{2} + \frac{1}{4} + 4(0.0025)^2\Big)t \qquad (29)$$

Table (1) shows the approximate solution using the proposed VITM method against the exact solution for various values of x and t.

Table (1): The Approximation Solution against the Exact Solution When $\alpha = \beta = 0.01$ and $\sigma = 1$.

x	t	Exact sol.	App. Sol.	Error
0.01	0.02	0.500043749999888	0.500037500312506	0.000006249687382
0.02		0.500031249999959	0.500025000312525	0.000006249687434
0.03		0.500018749999991	0.500012500312574	0.000006249687417
0.04		0.500006250000000	0.500000000312671	0.000006249687329
0.05		0.499993750000000	0.499987500312829	0.000006249687171
0.01	0.03	0.500068749999567	0.500062500703133	0.000006249296434
0.02		0.500056249999763	0.500050000703152	0.000006249296611
0.03		0.500043749999888	0.500037500703201	0.000006249296687
0.04		0.500031249999959	0.500025000703297	0.000006249296662
0.05		0.500018749999991	0.500012500703456	0.000006249296535
0.01	0.04	0.500093749998901	0.500087501250010	0.000006248748891
0.02		0.500081249999285	0.500075001250029	0.000006248749256
0.03		0.500068749999567	0.500062501250078	0.000006248749489
0.04		0.500056249999763	0.500050001250175	0.000006248749588
0.05		0.500043749999888	0.500037501250333	0.000006248749555
0.01	0.05	0.500118749997767	0.500112501953137	0.000006248044630
0.02		0.500106249998401	0.500100001953156	0.000006248045245
0.03		0.500093749998901	0.500087501953205	0.000006248045696
0.04		0.500081249999285	0.500075001953301	0.000006248045984
0.05		0.500068749999567	0.500062501953460	0.000006248046107
0.01	0.06	0.500143749996039	0.500137502812514	0.000006247183525
0.02		0.500131249996985	0.500125002812533	0.000006247184452
0.03		0.500118749997767	0.500112502812582	0.000006247185185
0.04		0.500106249998401	0.500100002812678	0.000006247185723
0.05		0.500093749998901	0.500087502812837	0.000006247186064
0.01	0.07	0.500168749993593	0.500162503828141	0.000006246165452
0.02		0.500156249994914	0.500150003828159	0.000006246166755
0.03		0.500143749996039	0.500137503828209	0.000006246167830
0.04		0.500131249996985	0.500125003828305	0.000006246168680
0.05		0.500118749997767	0.500112503828464	0.000006246169303
0.01	0.08	0.500193749990302	0.500187505000018	0.000006244990284
0.02		0.500181249992061	0.500175005000036	0.000006244992025
0.03		0.500168749993593	0.500162505000086	0.000006244993507
0.04		0.500156249994914	0.500150005000182	0.000006244994732
0.05		0.500143749996039	0.500137505000341	0.000006244995698

Case 2: when $\alpha = \beta = 0.001$ and $\sigma = 1$. Table (2) shows the approximate solution using the proposed VITM method against the exact solution for various values of x and t. In addition, the absolute errors resulted by using the proposed VITM and existing VIM [25] is presented.

Table (2): The Exact Solution and the Approximation Solution When $\alpha = \beta = 0.001$ and $\sigma = 1$.

x	T	Exact sol.	App. Sol.	**Error VITM**	Error VIM
0.01	0.02	0.500003812500000	0.500003750003125	0.000000062496875	0.0025031102
	0.04	0.500008812499999	0.500008750012500	0.000000062487499	0.0025081138
	0.06	0.500013812499996	0.500013750028125	0.000000062471871	0.0025131170
	0.08	0.500018812499991	0.500018750050000	0.000000062449991	0.0025181206
0.04	0.02	0.50000062500000	0.500000000003125	0.000000624996875	0.0099961959
	0.04	0.500005062500000	0.500005000012500	0.000000062487500	0.0100011899
	0.06	0.500010062499999	0.500010000028125	0.000000062471874	0.0100061907
	0.08	0.500015062499995	0.500015000050000	0.000000062449995	0.0100111915

5. Conclusion

The generalized Burger's-Fisher has been analyzed using the variational iteration transform method. The proposed method provides dependable results in the form of analytical approximation converging very rapidly, this method can give very good approximations by means of a few terms for most cases. The results showed a very strong mathematical tool for solving non-linear partial differential equations to get a large number of applications in engineering.

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الحل التقريبي لمعادلة بورجر – فشر بأستخدام طريقة التكرار التبايني التحويلي

علي الفياض

قسم الرياضيات وتطبيقات الحاسوب ، كلية العلوم ، جامعة النهرين ، بغداد ، العراق

الملخص

تمثل المعادلات التفاضلية الجزئية غير الخطية اهم الظواهر التي تحصل في العالم وتشترك في حقول العلوم المتنوعة. تعتبر معادلة بورجر– فيشر من المعادلات الاكثر اهمية لوصف مختلف الديناميكيات. تظهر معادلة بورجر– فيشر في حقل الرياضيات التطبيقية وتطبيقات الفيزياء. تمثل هده المعادلة النموذج الرئيس لوصف الترابط بين ميكانيكية التفاعل, التأثير الحراري والانتشار. في هذا البحث تم استخدام طريقة تحويل التكرار التبايني والتي تتألف من تحويلات لابلاس وطريقة تكرار التبايني لغرض الحصول على الحلول التحليلية التقريبية لمعادلة بوجر– فيشر. ان مقارنة النتائج المستحصلة باستخدام هذه الطريقه مع الحل التام والطرق الموجودة الاخرى تبين الدقة وسرعة التقارب للطريقة المقدمة.