**Modification of He's Variational Iteration Method and He's Homotopy Perturbation Method for Finding Approximate Solution of Nonlinear Fractional Integro-Differential Equations**

 Firas A. Al-Saadawi Ammar Muslim Abdulhussein

*firasamer519@yahoo.com* *ammar.muslim1@yahoo.com*

Department Mathematics, The Open Educational College, Basrah, Iraq.

***Abstract*** : Modification Variational iteration method and Homotopy perturbation method have been employed to obtain approximate solution nonlinear fractional integro-differential equations. Numerical examples are presented to illustrate the efficiency and accuracy of the proposed methods.

***Keywords:***Variational Iteration Method; Homotopy Perturbation Method; Boundary Value Problems; Integro-Differential Equations; Fractional Derivative; Caputo Sense.

1. **Introduction**

 In recent few decades, the fractional integro-differential equations attracted attention of the scientific community because of its play an important role in many branches of linear and nonlinear functional analysis and their applications in the theory of engineering, mechanics, physics, chemistry, astronomy, biology, economics, potential theory and electro statistics [5].

 There are many of techniques for the solution of fractional integro-differential equations, since it is relatively a new subject in mathematics, for example, Homotopy Perturbation Methods ([17],[19]), Variational iteration method ([18],[20]), Adomian decomposition method [13], Collection method [16], Legendre Wavelet method [19].

We will consider fractional order integro-differential equations of the form:

and

with the initial condition

for is a numerical parameter, where the function are known and is the unknown function, is Caputo’s fractional derivative and is a parameter describing the order of the fractional derivative and , is a nonlinear continuous function.

 The Homotopy perturbation method was established in 1998 by He ([7],[9-12]). The method is a powerful and efficient technique to find the solutions of nonlinear equations. The coupling of the perturbation and homotopy methods is called homotopy perturbation method. This method can take the advantages of the conventional perturbation method while eliminating its restrictions. In this method the solution is considered as the summation of an infinite series, which usually converges rapidly to the exact solutions.

 The Variational iteration method was first proposed 1998 by He ([1-3],[6],[8] ,[14],[15],[20]) and has found a wide application for the solution of linear and nonlinear differential equations, and was been worked out over a number of years by many authors. This method has been shown to effectively, easily and accurately solve a large class of nonlinear problems. Meanwhile, the Variational iteration method has been modified by many authors [1].

 In this Paper, we will find approximate solution to the nonlinear fractional integro-differential equations by using modified of He's Variational Iteration Method and He's Homotopy Perturbation Methods. It will show these methods are a useful and simplify tools to solve nonlinear fractional integro-differential equations as used in other fields.

**2.** **Preliminaries**

 In this section we present some basic definitions and properties of the fractional calculus theory, which are utilized in this paper[4,19].

**Definition 2.1:** A real function , is said to be in the space , if there exists a real number , such that , where , and it is said to be in the space if ; .

**Definition 2.2:** The Riemann-Liouville fractional integral operator of order of a function is defined as:

for and , some properties of the operator

**Definition 2.3:** The Caputo fractional derivative of is defined as:

for and , some properties of the operator ,

**Lemma:** If then the following two properties hold

**3. Analysis of the Modified Variational Iteration Method**

 For solving nonlinear fractional integro-differential equations withe initial conditions by constructing an initial trial-function without unknown parameters, we consider the following fractional functional equation

; (3.1)

where is the fractional order derivative, is a linear differential operator , and is the source term. By using the inverse operator to both sides of (3.1), and using the given conditions, we obtain

 (3.2)

where and the function represents the terms arising from integrating the source term and from using the given conditions, all are assumed to be prescribed.

The basic character of He's method is the construction of a correction functional for (3.1), which reads

; (3.3)

where is a Lagrange multiplier which can be identified optimally via variational theory [20], is the nth approximate solution, and denotes a restricted variation, i.e., : to solve (3.1) by He's VIM, we first determine the Lagrange multiplier that will be identified optimally via integration by parts. Then the successive approximations ; ; of the solution will be readily obtained upon using the obtained Lagrange multiplier and by using any selective function , The approximation may be selected by any function that just satisfies at least the initial and boundary conditions, with determined ; then several approximations ; ; follow immediately.

Consequently, the exact solution may be obtained by using

 (3.4)

In summary, we have the following variational iteration formula for (3.2)

 (3.5)

or equivalently, for (3.2), according to [6]:

 (3.6)

where the multiplier Lagrange , has been identified.

It is important to note that He's VIM suggests that the usually defined by a suitable trial-function with some unknown parameters or any other function that satisfies at least the initial and boundary conditions. This assumption made by He ([2],[20]) and others will be slightly varied, as will be seen in the discussion.

1. **Analysis of the Homotopy perturbation method**

 We consider the following nonlinear differential equation

 (4.1)

with boundary conditions

 (4.2)

where is a general differential operator, is a boundary operator, is a known analytical function, and is the boundary of the domain and is defined as follows:

 (4.3)

where is linear, while is nonlinear. Therefore (4.1) can be rewritten as follows

 (4.4)

Homotopy-perturbation structure is shown as:

 (4.5)

where and is an embedding parameter, is an initial approximation of (4.1), which satisfies the boundary conditions. By (4.5), it easily follows that

 , (4.6)

, (4.7)

and the changing process of from zero to unity is just that of H(v, p) from to . In topology, these is called deformation, and are called homotopic. The embedding parameter is introduced much more naturally, unaffected by artificial factors. Furthermore, it can be considered as a small parameter for . By applying the perturbation technique used in [12], we assume that the solution of (4.5) can be expressed as:

 (4.8)

 Therefore, the approximate solution of (4.1) can be readily obtained as follows:

 , (4.9)

 Equation (4.9) is the solution of equation (1) obtained by Homotopy perturbation method.

1. **Numerical examples**

 In this section, two examples are presented. The examples are nonlinear volterra integro-differential equations that using HPM and the results are compared with the exact solutions.

**Example 5.1**

 Consider the following nonlinear fractional integro-differential equation:

, (5.1.1)

where , with the initial condition , and exact solution .

 The solution according to (MVIM)

, (5.1.2)

 We take the operator on both sides of equation (5.1.1) we obtain:

, (5.1.3)

 According to the original VIM (3.3) and corresponding the recursive scheme (3.5), we obtain:

, (5.1.4)

, (5.1.5)

by assuming

 and

with starting of the initial approximation, , we obtain,

, (4.1.6)

in similarly view equation (5.1.6) it is obtained , where it is the exact solution of equation (5.1.1).

Now applying Homotopy perturbation method

, (5.1.2)

According to (1) we construct the following homotopy:

, (5.1.7)

.

.

.

by applying the operators to the above sets we obtain:

 , ,

Therefore the approximate solution of (5.1.1),

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *x* | *Exact* | *Approximant by MVIM* | *Error by (MVIM)* | *Approximant by (HPM)* | *Error by (HPM)* |
| 0.1 | 0.562341325 | 0.562341325 | 0 | 0.56233628 | 5.04541E-06 |
| 0.2 | 0.668740305 | 0.668740305 | 0 | 0.668632548 | 0.000107757 |
| 0.3 | 0.740082804 | 0.740082804 | 0 | 0.73943688 | 0.000645924 |
| 0.4 | 0.795270729 | 0.795270729 | 0 | 0.792969317 | 0.002301412 |
| 0.5 | 0.840896415 | 0.840896415 | 0 | 0.834730272 | 0.006166143 |
| 0.6 | 0.880111737 | 0.880111737 | 0 | 0.866316449 | 0.013795288 |
| 0.7 | 0.914691219 | 0.914691219 | 0 | 0.887438338 | 0.027252881 |
| 0.8 | 0.945741609 | 0.945741609 | 0 | 0.896589346 | 0.049152263 |
| 0.9 | 0.974003746 | 0.974003746 | 0 | 0.89131105 | 0.082692697 |
| 1 | 1 | 1 | 0 | 0.868306986 | 0.131693015 |

**Table 1:** The error and numerical results of the example 5.1 by using MVIM and HPM



**Figure 1**: Comparison numerical results obtained by MVIM and HPM of example 5.1

**Example 5.2**

 Consider the following nonlinear fractional integro-differential equation:

, (5.2.1)

where , with the initial condition , , and exact solution .

The solution according to (MVIM)

, (5.2.2)

We take the operator on both sides of equation (5.2.1) we obtain:

According to the original VIM (3.3) and corresponding the recursive scheme (3.5), we obtain:

, (5.2.3)

by assuming

 and

with starting of the initial approximation, , we obtain,

, (5.2.4)

 , ,

Then

in similarly view equation (5.2.4) it is obtained , where it is the exact solution of equation (5.2.1).

Now applying Homotopy perturbation method

, (5.2.5)

According to (2) we construct the following homotopy:

, (5.2.6)

.

.

.

by applying the operators to the above sets we obtain:

Therefore the approximate solution of (5.2.1),

**Table 2:** The error and numerical results of the example 5.2 by using MVIM and HPM

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *x* | *Exact* | *Approximant by MVIM* | *Error by (MVIM)* | *Approximant by (HPM)* | *Error by (HPM)* |
| 0.1 | 2.001 | 2.001 | 0 | 2.003571686 | 0.0025717 |
| 0.2 | 2.008 | 2.008 | 0 | 2.012359766 | 0.0043598 |
| 0.3 | 2.027 | 2.027 | 0 | 2.032867327 | 0.0058673 |
| 0.4 | 2.064 | 2.064 | 0 | 2.071180594 | 0.0071806 |
| 0.5 | 2.125 | 2.125 | 0 | 2.133338790 | 0.0083388 |
| 0.6 | 2.216 | 2.216 | 0 | 2.225364552 | 0.0093646 |
| 0.7 | 2.343 | 2.343 | 0 | 2.353272702 | 0.0102727 |
| 0.8 | 2.512 | 2.512 | 0 | 2.523073743 | 0.0110737 |
| 0.9 | 2.729 | 2.729 | 0 | 2.740775540 | 0.0117755 |
| 1 | 3 | 3 | 0 | 3.012384220 | 0.0123842 |

**Table 2:** The error and numerical results of the example 5.2 by using MVIM and HPM



**Figure 2:** Comparison numerical results obtained by MVIM and HPM of example 5.2

1. **Conclusions**

 In this work, we employed techniques MVIM and HPM to solve nonlinear fractional integro-differential equations successfully. The numerical results show that these methods have higher accuracy, good con­vergence with the exact solution and the results in MVIM are better than the results in HPM.

**References**

[1] T. Abassy, M. El-Tawil and H. Zoheiry, Solving nonlinear partial differential equations using the modified variational iteration-Pad technique, *J. Comput. Appl. Math. 207(2007), 73–91*.

[2] S. Abbasbandy, Numerical solution of non-linear Klein-Gordon equations by variational iteration method, *Internat. J. Numer. Methods Engrg. 70(2007), 876–881*.

[3] M. Dehghan, and M. Tatari, The use of Hes variational iteration method for solving the Fokker–Planck equation, *Phys. Scripta. 74 (2006), 310–316*.

[4] A. Elbeleze, A. Kilicman and B. Taib, Approximate solution of integro-differential equation of fractional (arbitrary) order, *J. of King Saud University – Science (2015), 1-8*.

[5] I. Hanan, The Homotopy Analysis Method for Solving Multi- Fractional Order Integro-Differential Equations, *J. of Al-Nahrain University, 14(3)(2011), 139-143*.

[6] J. He, Approximate analytical solution for seepage flow with fractional derivatives in porous media, *Comput. Methods Appl. Mech. Engrg. 167(1998), 57–68*.

[7] J. He, Homotopy perturbation technique, *Comut. Methods Appl. Mech. Engrg., 178(1999), 257-262*.

[8] J. He, Variational iteration method a kind of non-linear analytical technique: Some examples, *Internat. J. Nonlinear Mech. 34(1999), 699–708*.

[9] J. He, A coupling method of a Homotopy technique and a perturbation technique for non-linear problems, *Int. J. of Non-Linear Mechanics, 35(2000), 37-43*.

[10] J. He, Application of topological technology to construction of a perturbation system for a strongly nonlinear equation, *J. of the Juliusz Schauder Center, 20(2002), 77-83*.

[11] J. He, Homotopy perturbation method: a new nonlinear analytical technique, *Appl. Math. Comput., 135(2003), 73-79*.

[12] J. He, The Homotopy perturbation method for nonlinear oscillators with discontinuities, *Appl. Math. Comput., 151(2004), 287-292*.

[13] S. Momani, and S. Abuasad, Application of He’s variational iteration method to Helmholtz equation , *Chaos Soliton Fractals. 27 (2006), 1119–1123*.

[14] S. Momani, Z. Odibat and A. Alawneh, Variational iteration method for solving the spaceand time-fractional KdV equation, *Numer. Methods Partial Differential Equations. 24(1)(2008), 262–271*.

[15] R. Mittal, R. Nigam, Solution of fractional integro-differential equations by Adomian decomposition method, *Int. J. of Appl. Math. and Mech. 4(2)(2008), 87-94*.

[16] E. Rawashdeh, Numerical solution of fractional integro-differential equations by collocation method, *Appl. Math. Comput. 176(2006), 1–6*.

[17] R. Saeed, H. Sdeq, Solving a system of linear Fredholm fractional integro-differential equations using Homotopy perturbation methods, *Astralian J. of Basic Appl. Sc., 4(4)(2010), 633-638*.

[18] M. Saleh, D. Mohamed, M. Ahmed and A. Farhood, Approximate solution of nonlinear fractional integro-differential equations by He's Homotopy perturbation method and the modification of He's Variational iteration method, Math. *Theo. and Mod. 5(4)(2015), 168-181*.

[19] M. Saleh, A. Nagdy and M. Alngar, Legendre Wavelet and He's Homotopy Perturbation Methods for Linear Fractional Integro-Differential Equations, *Int. J. of Computer Appl. 110(10)(2015), 25-31*.

[20] S. Wang, and J. He, Variational iteration method for solving integrodifferential equtionas, *Phys Lett. A. 367(2007), 188–191*.