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Comparing the Solution of the Equations of Integral Volterra by the Method of Adomian Decomposition and Method of Series Solution and Method of Successive Approximations Numerically

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ABSTRACT

In this article, we try three a numerical techniques to solve nonlinear Volterra crucial equations of the second type, that is primarily based on the use of The Method of Series Solution (SSM), The Method of Adomian Decomposition (ADM) and The Method of Successive Approximations approach (SAM). They are very beneficial to obtain the solutions. We additionally show list a few numerical examples to reveal the effectiveness of the numerical methods. Our studies highlights the significance of the numerical techniques as these strategies are quick convergence of solutions. Furthermore, our evaluation led us to the willpower that any imperative equations may be solved by using those techniques without problems and all of the techniques led us about at one factor.

The results obtained through strategies had been compared with the other solution. Hence, ADM is observed to be a terrific device for the answer of Volterra necessary equations and additionally minimizes the volume of calculations.

MSC..

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1. Introduction

The equations of fundamental may be seen in lots of fields of mechanics, mathematics, physics, and solving a huge range of glitches throughout ample medical disciplines. By linking theory and application, this Ultimately the take a look at of numerical methods stands as an evidence to the power of mathematical evaluation in shaping our understandings of the sector and evolving clinical expertise. Volterra integral equations are known to occur in a variety of scientific domains, including viscoelastic materials and population dynamics. [5,6,8,9,11].

In Paper, The Method of Adomian Decomposition (ADM)., The Method of Series Solution (SSM). And The Method of Successive Approximations (SAM), Many teachers put it to use substantially to deal with algebraic equations, stochastic differential equations, integral equations, and everyday differential equations. [1,3,4]. (ADM),(SSM) and

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(SAM) are brought to offer the approximate solution for Volterra equations. Moreover it proves unique consequences and convergence of the solution . Volterra Integral Equations, characterized via their decrease integration limit being variable, frequently version structures with reminiscence effects, which includes population dynamics and viscoelastic substances. Conversely, ASM is applied to locate the approximation of analytical solution for nonlinear necessary equations. (ADM) is used to solve the Volterra Integral type, first off analytical factors are clarified after which used the operator shape obtained to solve problem of Volterra Integral kind . Additionally a few differences between the two techniques is executed for equal class of numerical equations. The Volterra Integral Equation has been broken down into an infinite number of components using the Adomian Decomposition Method.

However, we can substantially lessen this hard challenge thanks to recently discovered strategies. Therefore, it's far useful to outline a few sturdy and dependable methods so that it will ensure the achievement and value of reading nonlinear integral equations.

2. Methodology

In this have a look at, we focus on developing and comparing three analytical strategies for solving the nonlinear Volterra - the nonlinear- imperative equations of the second type. The preferred form of such equations is expressed as

$$v(r) = h(r) + \mu \int_0^r K\,(r, s) F\big(v(s)\big)\, ds$$

where $K(r,s)$ is the kernel function, $h(r)$ is a known function, μ is a real constant, and $F\big(v(s)\big)$ represents the nonlinear function such as v^2, v^3, $\sin(v)$, or e^v. The function which is unknown $v(r)$ appears both inside - outside the integral, making the equation nonlinear and often challenging to solve analytically.

To cope with this trouble, three wonderful analytical strategies are carried out and compared:

- The Method of Adomian Decomposition (ADM)
- The Method of Series Solution (SSM)
- Successive Approximations Method (SAM)

Each technique is systematically carried out to the same nonlinear Volterra crucial equation to affirm accuracy and convergence towards the exact analytical answer.

2.1 Adomian Decomposition Method (ADM)

The Adomian Decomposition Method is predicated on that the unknown feature v(r) may be expressed as an countless collection of components:

$$v(r) = \sum_{n=0}^{\infty} v_n (r)$$

The nonlinear operator F(v) is further improved in terms of Adomian polynomials A_n:

$$F(v) = \sum_{n=0}^{\infty} A_n$$

Each A_n is constructed recursively using the formula

$$A_n = \frac{1}{n!} \frac{d^n}{dh^n} \left[F \left(\sum_{i=0}^{n} h^i \, v_i \right) \right]_{h=0}$$

By substituting these expansions into the original Volterra equation, a recursive relation is received:

$$v_{n+1}(r) = \mu \int_0^r K\,(r,s) A_n(s)\, ds, \quad n \geq 0$$

with the initial term $v_0 = h(r)$.

The approximate analytical solution is then given by

$$v(r) \approx \sum_{n=0}^{m} v_n (r)$$

The ADM offers an green decomposition that avoids linearization or perturbation, making it pretty effective for nonlinear troubles.

2.2 The Method of Series Solution (SSM)

In this technique, the unknown characteristic v(r) is thought to have a Taylor series growth round $r = 0$:

$$v(r) = \sum_{n=0}^{\infty} a_n \, r^n$$

Substituting this growth into the fundamental equation and integrating time period by time period yields an algebraic recurrence relation many of the coefficients a_n.

By equating coefficients of identical powers of r on both facets, the coefficients $a_0, a_1, a_2, \ldots$ are determined recursively. Once these coefficients are acquired, substituting them again affords the approximate analytical solution:

$$v(r) = a_0 + a_1 r + a_2 r^2 + a_3 r^3 + \cdots$$

The accuracy of this technique increases as extra phrases are retained. For the test equation taken into consideration, the collection converges to the precise solution $v(r) = e^r$, confirming the validity of the method.

2.3 The Method of Successive Approximations (SAM)

This Method (additionally called Picard iteration) begins with an initial bet $v_0(r)$, normally a easy characteristic including 0, 1, or r. The iterative formula is defined as

$$v_{n+1}(r) = h(r) + \int_0^r K\,(r,s)F\big(v_n(s)\big)\,ds, \quad n \geq 0$$

Each new approximation is computed by means of substituting the previous one into the fundamental. This system is repeated till convergence, i.e.,

$$v(r) = \lim_{n\to\infty} v_n(r)$$

If the kernel $K\,(r,s)$ and the nonlinear feature F(v) satisfy the Lipschitz situation, the approach guarantees convergence to the specific specific solution.
In the examined example, successive iterations yield $v(r) = e^r$, verifying each the convergence and accuracy of the SAM technique.

2.4 Comparative Framework

The three analytical strategies had been implemented to the equal nonlinear Volterra imperative equation for comparative functions. The accuracy, convergence fee, and computational simplicity had been analyzed. The Adomian Decomposition Method (ADM) supplied speedy convergence with minimal computation. The Series Solution Method (SSM) provided analytical readability, even as the Successive Approximations Method (SAM) showed iterative stability and convergence closer to the same exact answers.

3. Result

3.1 The Nonlinear Volterra Integral Equations of the Second Kind

The investigation of The Nonlinear Volterra Integral Equations of the Second Kind begin by providing

$$v(r) = h(r) + \mu \int_0^r K(r,s)F(v(s))ds \qquad 1$$

Where is the kernel (r,s) , function is $h(r)$ are assigned functions with actual values. , μ constant and $F(v(s))$ is a function of nonlinear $v(s)$ like as $v^2, v^3, \sin(v), e^v$, etc.. The function $v(r)$ which is unknown, that happens both within and outside the integral indication, and will be decided.

Three different approaches will be used to solve the nonlinear Volterra equation. (1). The methods are the Adomian decomposition technique, the series solution method, and the successive approximations method.

3.2 The method of Adomian decomposition (ADM)

The method of Adomian decomposition [1,8] assumes that of decomposing the function of unknown $v(r)$ may be The infinite series is a representation of

$$v(r) = \sum_{n=0}^{\infty} v_n(r) \qquad 2$$

where the components $v_n(r)$, will be recursively computed. However, the nonlinear operator $F(v(s))$, can be expressed into an infinite series of the polynomials A_n given by

$$F(v(s)) = \sum_{n=0}^{\infty} A_n(r) \qquad 3$$

where the Adomian polynomials A_n Its capable of being assessed for all types of nonlinearity.

, defined by

$$A_n = \frac{1}{n!}\frac{d^n}{dh^n}\left[F(\sum_{i=0}^{n} h^i v_i(r))\right]_{h=0} \quad , n = 0,1,2,\dots \qquad 4$$

The total of the components' subscripts of v(r) of each time period of A_n is identical to n, as established via the brand new Adomian polynomials referred to above in (4).

It is now well known that certain techniques mentioned through [10] may be used to assemble these polynomials for all kinds of nonlinearity. Wazwaz has these days created an alternate approach for constructing Adomian polynomials [11].

we substitute (1) into equation (4) to get

$$\sum_{n=0}^{\infty} v_n(r) = h(r) + \mu \sum_{n=0}^{\infty} (\int_0^r K(r,s) A_n(s) ds) \qquad 5$$

The goal of the decomposition approach is to identify the components

$v_0, v_1,\dots, v_{n+1}$ are usually determined recursively by

$$v_0 = h(r)$$

$$v_1 = \int_0^r K(r,s)A_0(s)ds$$

$$v_2 = \int_0^r K(r,s)A_1(s)ds$$

$$v_{n+1} = \int_0^r K(r,s)A_n(s)ds\,, \qquad n \geq 0 \qquad 6$$

Then, $v(r) = \sum_{n=0}^{m} v_n(r)$ as the approximate solution.

Example 1

Applying the method of Adomian decomposition , the following nonlinear Volterra integral problem will be solved with

$$v(r) = e^r - \frac{1}{9}e^{3r} + \frac{1}{3}r + \frac{1}{9} + \int_0^r (r-s)v^3(s)\, ds \qquad 7$$

The Adomian polynomials (3) and the series (2) may be substituted into the left and right sides of (7), respectively, to obtain

$$\sum_{n=0}^{n} v_n(r) = e^r - \frac{1}{9}e^{3r} + \frac{1}{3}r + \frac{1}{9} + \int_0^r (r-s)(\sum_{n=0}^{\infty} A_n(s))\ ds \qquad 8$$

whereA_n the polynomials of Adomian for $v_n(r)$ as was cleared above. Applying the decomposition that was modified technique we set

$$v_0(r) = e^r$$

$$v_1(r) = -\frac{1}{9}e^{3r} + \frac{1}{3}r + \frac{1}{9} + \int_0^r (r-s)(\sum_{n=0}^{\infty} A_n(s))\ ds = 0$$

The next components $v_2(r)$ disappear as a result. Thus, the precise answer is provided by

$$v(r) = e^r$$

Example 2

Use the Adomian decomposition method to solve the following nonlinear Volterra integral problem.

$$v(r) = cos(r) + \frac{1}{8}cos(2r) - \frac{1}{4}r^2 - \frac{1}{8} + \int_0^r (r-s)v^2(s)\, ds \qquad 9$$

Substituting the series (2) and the Adomian polynomials (3) into the left side and the right side of (9) respectively gives

$$\sum_{n=0}^{n} v_n(r) = cos(r) + \frac{1}{8}cos(2r) - \frac{1}{4}r^2 - \frac{1}{8} + \int_0^r (r-s)\sum_{n=0}^{\infty} A_n(s))\ ds \qquad 10$$

where A_n is the Adomian polynomials to $v_n(r)$as shown before. To use the modified of decomposition method we set

$$v_0(r) = cos(r) + \frac{1}{8}\cos(2r)$$

$$v_1(r) = -\frac{1}{4}r^2 - \frac{1}{8} + \int_0^r (r-s)A_0(s)ds$$

$$v_1(r) = -\frac{1}{4}r^2 - \frac{1}{8} + \int_0^r (r-s)v^2{}_0(s)ds = -\frac{1}{8}cos(r)$$

$$v_{n+1}(r) = \int_0^r (r-s)A_n(s)ds \quad , n \geq 1$$

We can see how the noise words occur.

$\frac{1}{8}cos(r)$ and $-\frac{1}{8}cos(r)$ between $v_0(r)$and $v_1(r)$respectively. With canceling the noise term $\frac{1}{8}cos(r)$ from $v_0(r)$, we can show that

$$v(r) = cos(r)$$

is the same solution that satisfies the equation of integral.

3.3 The Method of Series Solution

The equations of Volterra integral the nonlinear will be treated in this part using a similar application of the series solution approach[3,4,9]. In consideration which the Taylor series' generic form at $r = 0$ can be written as

$$v(r) = \sum_{n=0}^{\infty} a_n r^n \qquad 11$$

Will be assumed that the solve $v(r)$ of the nonlinear integral Volterra equation

$$v(r) = h(r) + \int_0^r K(r,s)F\big(v(s)\big)ds \qquad 12$$

Substituting (11) into all sides of (12) gives

$$\sum_{n=0}^{\infty} a_n r^n = T\big(h(r)\big) + \int_0^r K(r,s)F\left(\sum_{n=0}^{\infty} a_n s^n\right)ds \qquad 13$$

or for simpleness we use

$$a_0 + a_1 r + a_2 r^2 + \cdots = T(h(r)) + \int_0^r K(r,s)F(a_0 + a_1 s + a_2 s^2 + \cdots)ds \qquad 14$$

where the Taylor series for $h(r)$ is $T(h(r))$. The equation of integral (12) would be changed into a traditional integral in (14) or (13) where we replace integrating the nonlinear term $F(h(r))$ terms of the form s^n, n ≥ 0 would be integrated.

In (13) or (14), we firstly, integrate the integral's right side before gathering the coefficients of similar powers of r. A relation of recurrence is then obtained by comparing the coefficients of comparable powers of r on both sides of the formula resulted in a_i, i ≥ 0.

The coefficients will be fully determined after the recurrence relation is solved.

a_i, i ≥ 0.. When the obtained coefficients are substituted, the series solution appears instantly into (14). In this instance, our level of accuracy increases with the number of words we identify.

Example 3

The following nonlinear Volterra integral issue may be solved using the series solution method.

$$v(r) = e^r - \frac{1}{9}e^{3r} + \frac{1}{3}r + \frac{1}{9} + \int_0^r (r-s)v^3(s)\,ds \qquad 15$$

Applying (14)'s series form to both sides of (15) yields

$$a_0 + a_1 r + a_2 r^2 + \cdots = e^r - \frac{1}{9}e^{3r} + \frac{1}{3}r + \frac{1}{9} + \int_0^r (r-s)(a_0 + a_1 s + a_2 s^2 + \cdots)^3 ds \qquad 16$$

The integral is being integrated on the right side. (16), to use the series Taylor of e^r and e^{3r} , and Comparing the similar powers coefficients of r we obtain

$$a_0 = 1 \ , a_1 = 1$$

$$a_2 = \frac{1}{2!}{a_0}^2 = \frac{1}{2!}$$

$$a_3 = -\frac{1}{3} + \frac{1}{2}{a_0}^2 a_1 = \frac{1}{3!}$$

$$a_4 = -\frac{1}{3} + \frac{1}{4}a_0({a_1}^2 + a_0 a_2) = \frac{1}{4!}$$

$$\vdots$$

$$a_n = \frac{1}{n!}$$

When the coefficients of like powers of r on both sides are equal, the result is

$$v(r) = 1 + r + \frac{1}{2!}r^2 + \frac{1}{3!}r^3 + \cdots$$

The same solution is given by $v(r) = e^r$

Example 4

To solve the next nonlinear equation of Volterra integral with using the series solving method

$$v(r) = cos(r) + \frac{1}{8}cos(2r) - \frac{1}{4}r^2 - \frac{1}{8} + \int_0^r (r-s)v^2(s)\,ds \qquad 17$$

To use the series form (13) into both sides of (17) gives

$$a_0 + a_1 r + a_2 r^2 + \cdots = cos(r) + \frac{1}{8}cos(2r) - \frac{1}{4}r^2 - \frac{1}{8} + \int_0^r (r-s)(a_0 + a_1 s + a_2 s^2 + \cdots)^2 ds \qquad 18$$

Integrating the integral on the right side (18), using the Taylor series of $cos(r)$ and $cos(2r)$, and equating the coefficients of like powers of r we obtain

$$a_0 = 1 \quad , a_1 = 0$$

$$a_2 = \frac{1}{2!}{a_0}^2 = -\frac{1}{2!}$$

$$a_3 = -0 + \frac{1}{2}{a_0}^2 a_1 = 0$$

$$a_4 = -\frac{1}{3} + \frac{1}{4}a_0({a_1}^2 + a_0 a_2) = \frac{1}{4!}$$

$$\vdots$$

Equating the coefficients of like powers of r in both sides yields

$$v(r) = 1 - \frac{1}{2!}r^2 + \frac{1}{3!}r^4 + \cdots$$

The exact solution is given by $v(r) = \cos(r)$

3.4 The Method of Successive Approximations

Any difficulty may be solved using the successive approximations method [2,5,11] by using starting with the zeroth approximation, which is a preliminary estimate. This first estimate may be any selected real-valued feature so as to be utilized use a recurrence relation to determine the subsequent approximations. Considering the second-kind nonlinear Volterra indispensable equation.

$$v(r) = h(r) + \int_0^r K(r,s)F\big(v(s)\big)ds \qquad 19$$

The recurrence relation is introduced using the successive approximations approach.

$$v(r) = h(r) + \int_0^r K(r,s)F\big(v(s)\big)ds\,, \quad n \geq 0 \qquad 20$$

Where the approximation of zero $v_0(r)$ may be the selective actual valued function. We start with guess is the begining for $v_0(r)$, basically we pick out 0,1, or r for $v_0(r)$ Using this selection of $v_0(r)$, into (20), many successive approximations $v_n(r), n \geq 1$ could be determined as

$$v_1(r) = h(r) + \int_0^r K(r,s)F\big(v_0(s)\big)ds$$

$$v_2(r) = h(r) + \int_0^r K(r,s)F\big(v_1(s)\big)ds$$

$$\vdots$$

$$v_{n+1}(r) = h(r) + \int_0^r K(r,s)F\big(v_n(s)\big)ds \qquad 21$$

Consequently, the solution $v(r)$ is decleared by using

$$v(r) = \lim_{n\to\infty} v_{n+1}(r) \qquad 22$$

The convergence of $v_{n+1}(r)$

The following examples will serve as an illustration of the SAM.

Example 5

The nonlinear Volterra integral problem can be resolved by applying the successive approximations approach.

$$v(r) = e^r - \frac{1}{9}e^{3r} + \frac{1}{3}r + \frac{1}{9} + \int_0^r (r-s)v^3(s)\,ds \qquad 23$$

For the approximation of zero $v_0(r)$, we can select

$$v_0(r) = 1$$

The iteration formula can be used with the successive approximation approach.

$$v_{n+1}(r) = e^r - \frac{1}{9}e^{3r} + \frac{1}{3}r + \frac{1}{9} + \int_0^r (r-s){v_n}^3(s)\, ds, \qquad n \geq 0 \qquad 24$$

Substituting (23) into (24)

we obtain the approximations

$$v_0(r) = 1$$

$$v_1(r) = e^r - \frac{1}{9}e^{3r} + \frac{1}{3}r + \frac{1}{9} + \int_0^r (r-s){v_0}^3(s)\, ds$$

$$v_1(r) = 1 - \frac{1}{2}r^2 + \frac{1}{4!}r^4 - \frac{1}{240}r^6 + \cdots$$

$$v_2(r) = e^r - \frac{1}{9}e^{3r} + \frac{1}{3}r + \frac{1}{9} + \int_0^r (r-s){v_1}^3(s)\, ds$$

$$v_2(r) = 1 - \frac{1}{2}r^2 + \frac{1}{4!}r^4 - \frac{1}{240}r^6 + \cdots$$

And so on

As a result , the solution $v(r)$ of (24) is given by

$$v(r) = \lim_{n\to\infty} v_n(r) = e^r$$

Example 6

The nonlinear Volterra integral problem may be solved using the successive approximations approach.

$$v(r) = cos(r) + \frac{1}{8}cos(2r) - \frac{1}{4}r^2 - \frac{1}{8} + \int_0^r (r-s)v^2(s)\, ds \qquad 25$$

For the zeroth approximation $v_0(r)$, we can select

$$v_0(r) = 1$$

The method of successive approximations admits the use of the iteration formula

$v_{n+1}(r) = cos(r) + \frac{1}{8}cos(2r) - \frac{1}{4}r^2 - \frac{1}{8} + \int_0^r (r-s){v_n}^2(r)\, ds, n \geq 0$ 26

Substituting (25) into (26)

we get approximations

$v_0(r) = 1$

$$v_1(r) = cos(r) + \frac{1}{8}cos(2r) - \frac{1}{4}r^2 - \frac{1}{8} + \int_0^r (r-s)(1)^2\, ds \quad , n \geq 0$$

$$v_1(r) = 1 - \frac{1}{2!}r^2 + \frac{1}{8}r^4 - \frac{1}{80}r^6 + \cdots$$

$$v_2(r) = cos(r) + \frac{1}{8}cos(2r) - \frac{1}{4}r^2 - \frac{1}{8} + \int_0^r (v-s){v_1}^2(s)\, ds \quad , n \geq 0$$

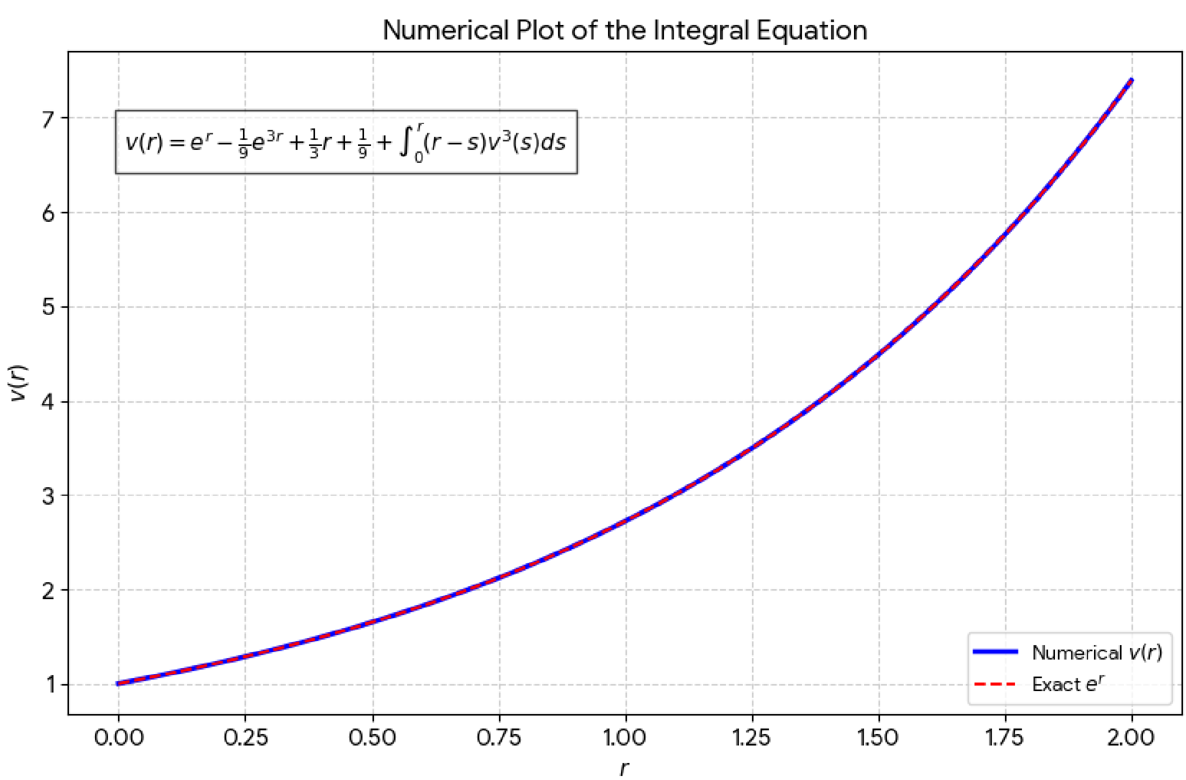
$$v_2(r) = 1 - \frac{1}{2!}r^2 + \frac{1}{4!}r^4 - \frac{1}{240}r^6 + \cdots$$

$$v_3(r) = 1 - \frac{1}{2!}r^2 + \frac{1}{4!}r^4 - \frac{1}{6!}r^6 + \cdots$$

Consequently, the solution $v(r)$ of (26) is given by

$$v(r) = \lim_{n\to\infty} v_n(r) = \cos(r)$$

Fig 1. Graphical representation of Numerical Examples 1,3,5



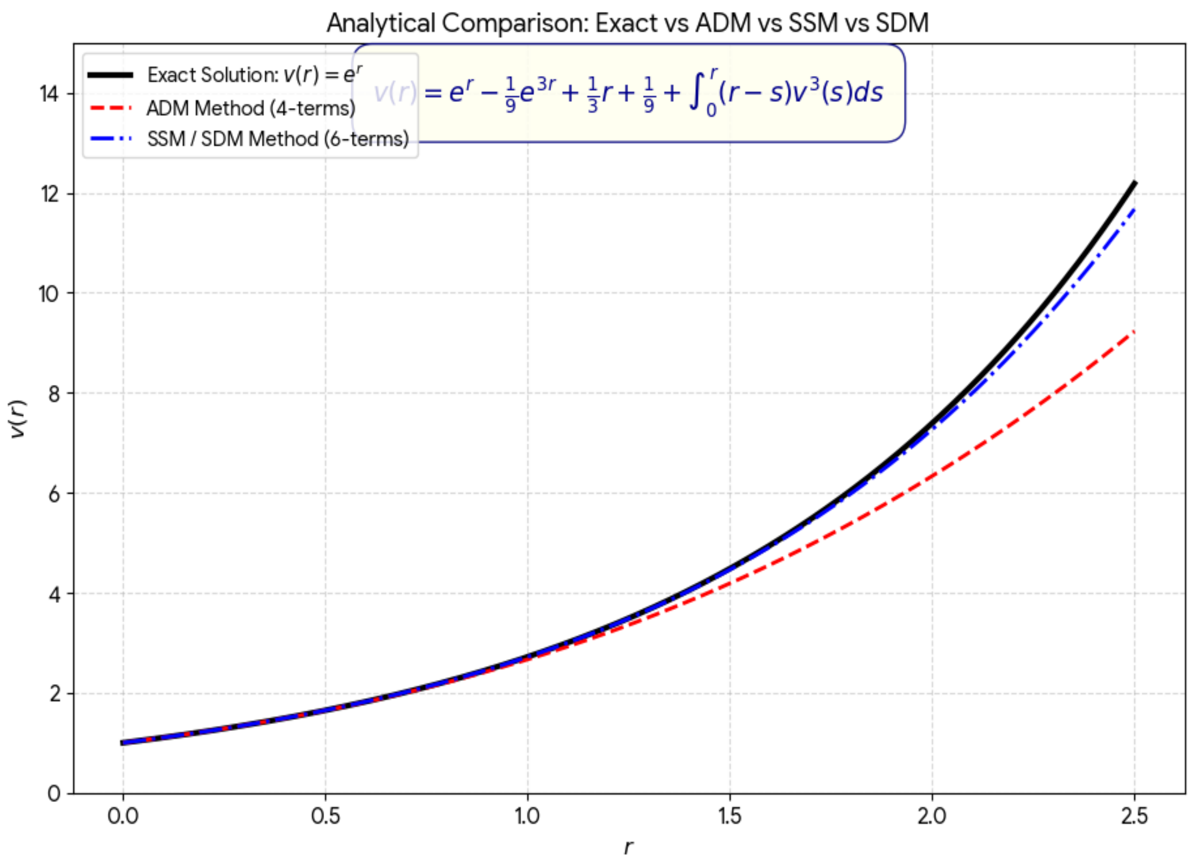
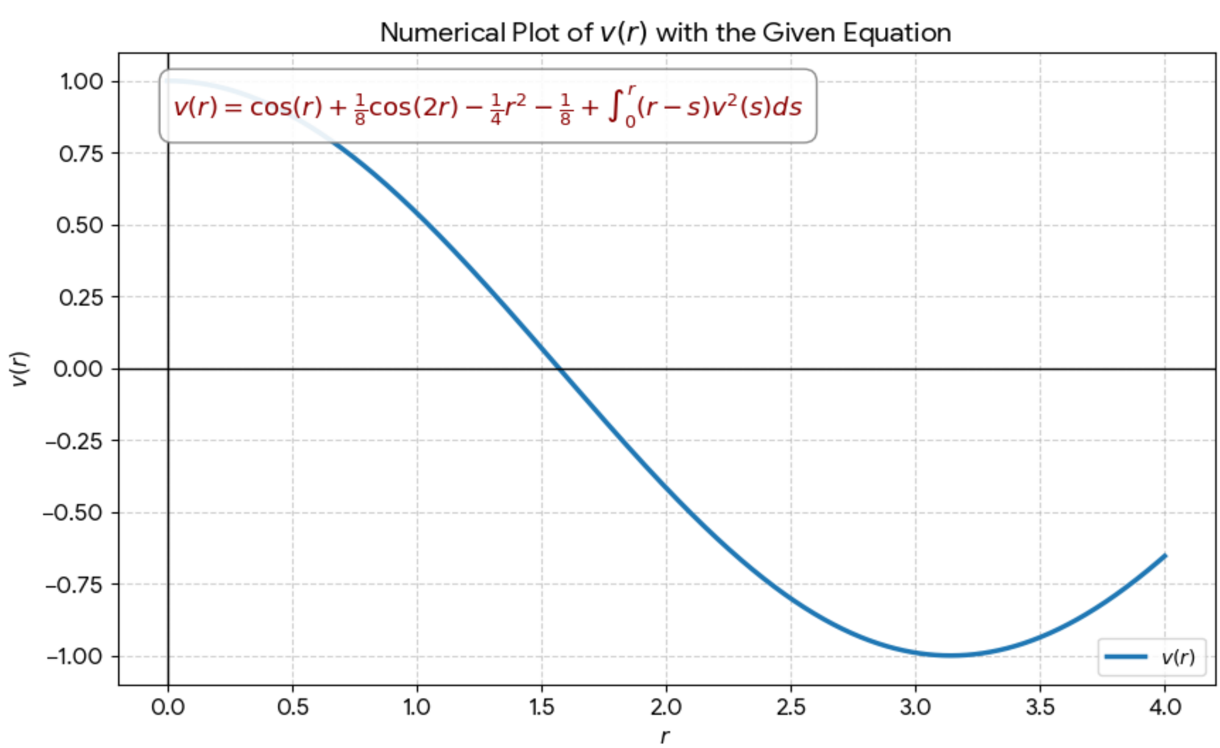
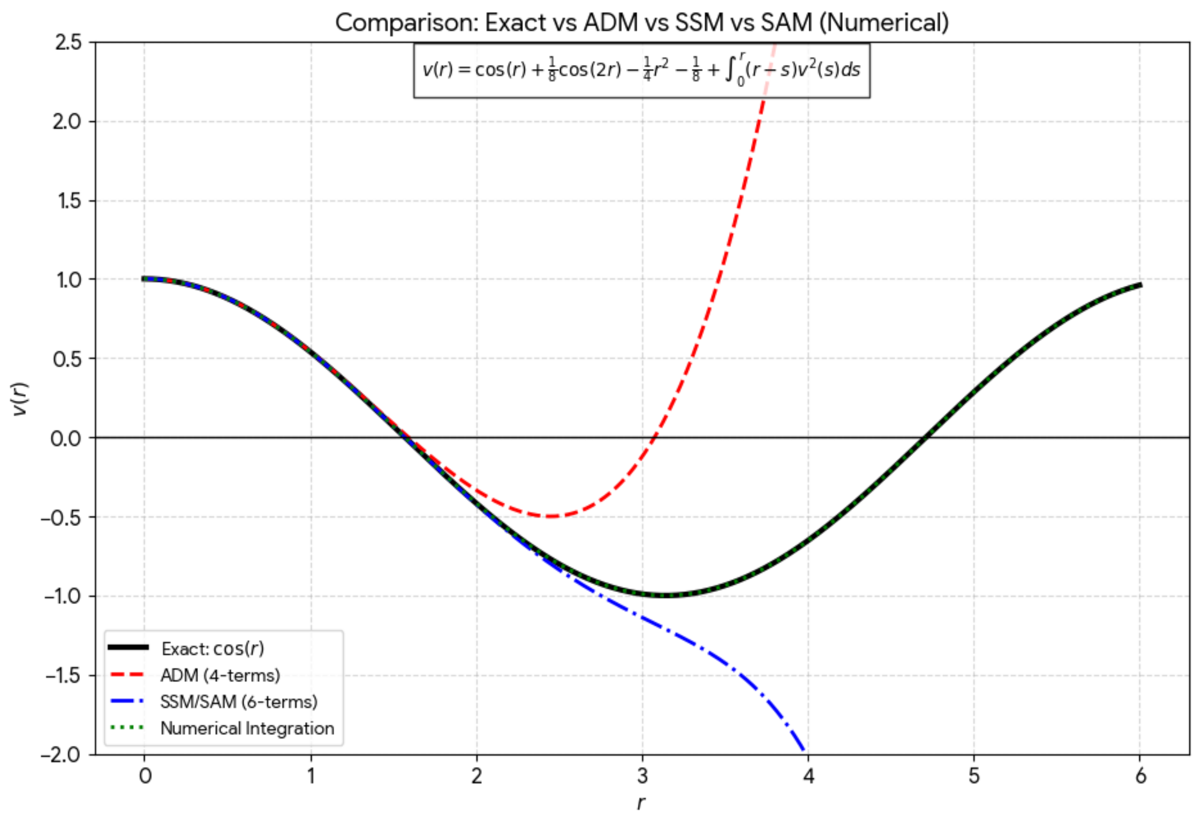


Fig 2. Graphical representation of Numerical Examples 2,4,6





4- Conclusion

In this article, we present a numerical methods for solving integral equations which is based on the use of ADM,ASM and SSM. We apply it successfully to solve nonlinear Volterra second kind integral equations. The methods can be used to solve other integral and equations. In this look at, three powerful analytical methods—the Adomian Decomposition Method (ADM), the Series Solution Method, and the Successive Approximations Method (SAM)—had been implemented to resolve a nonlinear second-kind Volterra critical equation, with a particular test example whose actual solution is understood to be $v(r)=e^r$. The outcomes validated that every one three methods efficiently converged to the precise answer, notwithstanding differences of their computational mechanisms, convergence rates, and implementation complexity. The Adomian Decomposition Method achieved high accuracy by using systematically decomposing the nonlinear time period into Adomian polynomials, allowing direct recursive computation of answer components without linearization or perturbation. This makes ADM particularly effective for complex nonlinearities along with v^3, sin(v) , or e^v The Series Solution Method, then again, excelled in extracting specific analytical expressions by way of equating coefficients of like powers of r within the Taylor expansions of both sides of the equation. It supplied a clear, step-by way of-step derivation of the solution's series form, in the long run yielding the exact closed-shape solution e^r with minimum approximation. Meanwhile, the Successive Approximations Method, even though the maximum truthful in idea, required iterative substitution starting from an preliminary bet ($v_0(r)=1$). Despite slower initial convergence, it progressively approached the precise answer, confirming its robustness and reliability even with out earlier know-how of the solution structure. The reality that each one three strategies independently reproduced the precise answer $v(r)=e^r$ not only validates their mathematical correctness but also highlights their complementary strengths: ADM for handling complicated nonlinearities, the Series Method for deriving closed-form analytical solutions, and SAM for its simplicity and balance beneath minimal assumptions. This comparative evaluation underscores that the choice of method must be guided by means of the character of the trouble: ADM is ideal for complicated nonlinear systems requiring dependent decomposition; the Series Method is favored when an analytical collection illustration is preferred; and SAM remains a dependable, smooth-to-implement alternative for troubles in which computational simplicity is prioritized over velocity. In end, this paintings demonstrates the efficacy and versatility of classical analytical techniques in fixing nonlinear Volterra vital equations. It reinforces their cost as foundational tools in carried out mathematics and encourages their extension to more complicated situations—which include equations with variable kernels, integro-differential systems, or non-homogeneous boundary situations—specially while included with numerical algorithms for better computational performance and quantitative convergence evaluation. Future research should focus on automating these methods via symbolic computation software program and expanding their software to actual-international models in physics, engineering, and biology, where memory-established nonlinear dynamics are generic.

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