Numerical investigation of the Adomian-based methods with w-shaped optical solitons of Chen-Lee-Liu equation

A S H F Mohammed and H O Bakodah
Department of Mathematics, Faculty of Science - University of Jeddah, Jeddah, Saudi Arabia
E-mail: ashmohamad@uj.edu.sa and hobakodah@uj.edu.sa

Keywords: Chen-Lee-Liu equation, Adomian decomposition method, w-shaped solitary waves, improved Adomian decomposition method

Abstract
The present paper computationally examines the w-shaped solitary wave solutions for an important type of nonlinear Schrödinger equation that appeared in 1979 called the Chen-Lee-Liu (CLL) equation by proposing two recursive schemes. The schemes are based on the famous Adomian’s efficient decomposition technique. We successfully simulated the two proposed schemes with the aid of mathematical software and established a comparative analysis. It is noted from the present study that the improved method performs better than the classical method at different time levels. This is in fact in conformity with most of the results in the related literature. We finally present tables and a series of figures to support the presented results.

1. Introduction
The study of soliton solutions corresponding to nonlinear evolution equations helps a lot in understanding certain interesting physical properties posed by the equations. The homogeneous balance involving the highest-nonlinear term and the highest-linear term arising in such evolution equations causes the shape of soliton wave pulses not to change during propagation [1, 2]. Generally, the nonlinear Schrödinger equation is an important class of evolution equations that plays a vital part in the study of diverse areas of nonlinear sciences such as nonlinear optics, plasma physics and optical fibers among others. Besides, these equations explain the pulse dynamics in optical fibers [3, 4]. Furthermore, various computational, semi-analytical and analytical methods have been proposed and used in the past decades to examine many classes of Schrödinger equations, see [3–22] and the references therein. However, a class of nonlinear Schrödinger equation with a great number of applications is the so-called Chen-Lee-Liu equation given in dimensionless form as [23]

\[ iu_t + au_{xx} + ib\ |u|^2 u_x = 0, \tag{1.1} \]

with \( u(x, t) \) designating the soliton’s profile in space and time variables \( x \) and \( t \); while and \( a \) and \( b \) are nonzero constants standing for the group velocity dispersion and self-steepening phenomena, correspondingly. Moreover, when \( a = b = 1 \), equation (1.1) reduces to a Regular Chen-Lee-Liu (RCLL) equation as extensively examined in [23]. The CLL model emanated from the extension of the classical nonlinear Schrödinger equation to accommodate more applications in the propagation and interaction of ultrashort pulses in optics. More, various numerical methods were used to study many mathematical models including the standard Adomian decomposition method [24] and the improved Adomian decomposition method introduced by [25] for CLL model with some cases bright optical solitons [19, 26]. Also, this model was solved by Adomian-based Methods introduced by Wazwaz and El-Sayed [27, 28] with different kinds of optical solitons [29, 30]. Furthermore, the w-shaped optical soliton of CLL equation studied only by Laplace Adomian decomposition method [5]. However, in the present paper, we numerically study the w-shaped optical soliton solution of the CLL equation. We derive two recursive schemes based on the Adomian’s efficient algorithm by Wazwaz [24] and the other by improved Adomian’s method [25]. A comparative analysis of the two methods will be carried out by extensively...
examining the absolute errors posed by the schemes. We further aim to submit a comprehensive conclusion at the end. Besides, it is also pertinent to mention here that there other numerical or rather semi-analytical methods that go hand-in-hand with the Adomian’s method in solving vast classes of nonlinear differential and evolution equations. These methods include the homotopy perturbation method, homotopy analysis method, variational iteration method and transform-based decomposition methods to mention a few, see \[31–36\]. Also, the arrangement of the paper takes the following form: we recall an exact w-shaped optical soliton solution in section 2. In section 3, we give the outlines of the two methods. Also, in section 4, we discuss the obtained numerical results; while section 5 presents some concluding remarks.

2. The w-shaped optical solitary waves

In this section, we present the recently obtained exact solution in the form of w-shaped soliton of the CLL equation by Triki \textit{et al} \[9\] given by

\[ u(x, t) = \sqrt{\gamma \pm \eta} \text{sech}[\lambda(x - vt)] e^{i(-4x + \omega t + \theta(x - vt))}, \]

where \( \gamma \), \( \eta \) and \( \lambda \) are parameters defined by the following formulae:

\[
\gamma = \frac{a_2}{4a_3}, \quad \eta = \sqrt{\frac{3a_2^2 + 8a_1a_3}{8a_3^2}}, \quad \lambda = \sqrt{\frac{3a_2^2 + 8a_1a_3}{8a_3^2}},
\]

with

\[
a_1 = \frac{bB - v^2}{a^2} + \frac{4\omega - 4vk}{a}, \quad a_2 = \frac{bv}{2a^2}, \quad a_3 = \frac{b^2}{4a^2},
\]

where \( a, b, B, k, v \) and \( \omega \) are arbitrary constants; while \( a_1, a_2 \) and \( a_3 \) are constants satisfying the constraint conditions \( 3a_2^2 + 8a_1a_3 > 0 \) and \( a_3 > 0 \). The w-shaped soliton of the CLL equation presented in equation (2.1) will be used in the subsequent section as a benchmark solution for the numerical investigation and comparison of the ADM and IADM methods, respectively. In particular, equation (2.1) gives the expressions for two dissimilar bright pulses of the CLL equation earlier given in equation (1.1). The parameter \( \eta \) is an important factor that determines the nature of the propagating profile for the wave in the background. If for instance we further analyze the \((-\) signed solution given from equation (2.1), it is easy to clearly notice that the soliton’s profile looks exactly like the letter w. It is however noted that the profile maintains unaffected for significantly long distance while propagating. In the same manner, the \((+\) signed solution given from equation (2.1) is also a bright soliton solution of the CLL equation \[9\].

3. Numerical solutions

In this section, we derive the numerical recursive schemes for the CLL equation by employing both the ADM and IADM methods.

3.1. Adomian Decomposition Method (ADM)

We adopted the version of the ADM introduced by Wazwaz in \[24\]. First, consider again the CLL equation as follows

\[ u_t + aiu_{xx} - b |u|^2u_x = 0. \]

Then, on using the operator notation, let \( L_t = \frac{\partial}{\partial t} \) with its inverse operator \( L_t^{-1} = \int_0^t (\cdot) dt \), equation (3.1) becomes

\[ u = u(x, 0) + ai \int_0^t L_t^{-1}u_{xx} - b L_t^{-1}u_x, \]

where the nonlinear term in equation (3.2) is expressed by

\[ A = N(u) = |u|^2u_x, \]

Further, the decomposition method expresses the solution of the equation using an infinite series defined by

\[ u = \sum_{n=0}^{\infty} u_n, \]
and the nonlinear term in equation (3.2) is decomposed as

\[ A = \sum_{n=0}^{\infty} A_n, \]  

where \( A_n \)'s are the Adomian’s polynomials given by

\[ A_n = \frac{1}{n!} \frac{d^n}{dx^n} \left[ N \left( \sum_{i=0}^{\infty} X u_i \right) \right]_{x=0}, \ n = 0, 1, 2, \ldots \]  

Now, putting equations (3.4) and (3.5) into equation (3.2), we have

\[ u = \sum_{n=0}^{\infty} u_n = u(x, 0) + ai L_i^{-1} \sum_{n=0}^{\infty} u_{n_1} + b L_i^{-1} \sum_{n=0}^{\infty} A_n, \]  

and accordingly obtain the following solution recursively given by

\[ u_0(x, t) = u(x, 0), \]  
\[ u_{k+1}(x, t) = ai \int_0^t [ u_{k}(x, t) ] dt - b \int_0^t A_k dt, \ k \geq 0. \]  

Therefore, the targeting recursive scheme via the application of the ADM is thus given in equations (3.8) – (3.9). The scheme will then be simulated together with certain exact w-shaped soliton solutions in the subsequent section.

3.2. Improved Adomian Decomposition Method (IADM)

The IADM was proposed by [25] while converting the complex-valued equation of equation (1.1) type into a real-valued equation by splitting the complex-valued function \( u(x, t) \) as follows

\[ u(x, t) = u_1 + iu_2, \]  

where \( u_1 = u_1(x, t) \) and \( u_2 = u_2(x, t) \) are functions of real-values. Putting equation (3.10) into equation (3.1) yields the system as follows

\[ u_{1t} + au_{2xx} + b(u_1^2 + u_2^2)u_{1x} = 0, \]  
\[ u_{2t} - au_{1xx} + b(u_1^2 + u_2^2)u_{2x} = 0, \]  

with \( u_1(x, 0) = [u(x, 0)]_R, \) \( u_2(x, 0) = [u(x, 0)]_I, \) where \( R \) and \( I \) represent the real and imaginary Components of the complex function \( u(x, 0), \) respectively. Furthermore, we decompose the solutions into infinite series as follows

\[ u_i = \sum_{n=0}^{\infty} u_{i_n}, \ i = 1, 2, \]  

with \( u_{i_n} \) and \( u_{j_n} \) for \( n \geq 0 \) are to be determined, and we further represent the nonlinear expression in equations (3.11) and (3.12) by

\[ A_1 = b(u_1^2 + u_2^2)u_{1x} \]  
\[ A_2 = b(u_1^2 + u_2^2)u_{2x} \]

Also applying the corresponding inverse operator in equations (3.11) and (3.12) through equations (3.14) – (3.15) take the form

\[ u_1(x, t) = u_1(x, 0) - a L_i^{-1} u_{2xx} - L_i^{-1} A_1, \]  
\[ u_2(x, t) = u_2(x, 0) + a L_i^{-1} u_{1xx} - L_i^{-1} A_2. \]  

On substituting equation (3.13) and the decomposed nonlinear terms in equations (3.16) and (3.17) given in equation (3.6) we arrived at the following recursive scheme

\[ u_{1,0}(x, t) = u_1(x, 0), \]  
\[ u_{2,0}(x, t) = u_2(x, 0), \]
\[
\begin{align*}
    u_{1,k+1}(x, t) &= -a \int_0^t (u_{2,k}(x, t))_{xx} dt - \int_0^t A_{1,k} dt \quad k \geq 0, \\
    u_{2,k+1}(x, t) &= a \int_0^t (u_{1,k}(x, t))_{xx} dt - \int_0^t A_{2,k} dt \quad k \geq 0,
\end{align*}
\]

(3.20)

(3.21)

where \(A_{1k}, A_{2k}\) are the Adomian’s polynomials [37] to be recurrently computed from equation (3.6). Therefore, the targeting recursive scheme via the application of the IADM is thus given in equations (3.18) – (3.21). The scheme will then be simulated together with certain exact w-shaped soliton solutions in the subsequent section.

4. Results of numerical analysis

The present section gives numerical results of the obtained schemes and establishes some comparative study. Considering one of the w-shaped soliton solutions of the CLL equation for \(\eta > 0\) given in equation (2.1), that is,

\[
u(x, t) = \sqrt{2} \pm \\eta \operatorname{sech}(\lambda(x - vt)) e^{i(-kx + \omega t + \theta(x - vt))},
\]

with the corresponding initial condition

\[
u(x, 0) = \sqrt{2} \pm \\eta \operatorname{sech}(\lambda x) e^{i(-kx)},
\]

we are able to numerically simulate the two recursive schemes for the ADM and IADM with the help of the Maple software and present the corresponding absolute error analysis in tables 1 and 2, and their respective graphical representations in figures 1–8. From the error analysis in tables 1 and 2, it is observed that the IADM performs better than the ADM as fully documented in the literature looking at the error discrepancies both when and. Also in figures 1, 2, 5 and 6, we give the absolute error comparisons of the considered exact W-shaped soliton and the approximate solutions using the ADM and IADM, respectively; while figures 3, 4, 7 and 8 give the three-dimensional (3D) surface of the numerical solutions in the same manner.

Furthermore, the graphical representations corresponding to the bright optical soliton solutions under consideration turned to look like a bell-shaped profile as in case (1) and w-shaped profile for case (2). This in fact depicts the physics behind the dynamics of each solution and will certainly give more insight while digging more information about the CLL equation with regards to interactions and propagations of pulses. We thus remarked here that the two schemes are efficient since they reveal good results with high level of exactness.

**Case (1).** Consider the positive-signed solution \((+\) given by

\[
u(x, t) = \sqrt{2} + \\eta \operatorname{sech}(\lambda(x - vt)) e^{i(-kx + \omega t + \theta(x - vt))}.
\]

| \(x\) | \(t = 0.3\) | Error ADM | Error IADM | Error ADM | Error IADM |
|------|----------|-----------|------------|-----------|------------|
| –5   | 1.479082800 \(10^{-6}\) | 8.3200 \(10^{-8}\) | 2.465142533 \(10^{-6}\) | 1.3878 \(10^{-7}\) |
| –4   | 1.480802200 \(10^{-6}\) | 6.6570 \(10^{-8}\) | 2.468093616 \(10^{-6}\) | 1.109 \(10^{-7}\) |
| –3   | 1.480857140 \(10^{-6}\) | 4.9950 \(10^{-8}\) | 2.468098072 \(10^{-6}\) | 8.3570 \(10^{-8}\) |
| –2   | 1.481414472 \(10^{-5}\) | 3.3320 \(10^{-8}\) | 2.469023851 \(10^{-6}\) | 5.5650 \(10^{-8}\) |
| –1   | 1.481747042 \(10^{-6}\) | 1.6720 \(10^{-8}\) | 2.469579371 \(10^{-6}\) | 2.9790 \(10^{-8}\) |
| 0    | 1.481857952 \(10^{-6}\) | 1.0000 \(10^{-10}\) | 2.469763257 \(10^{-6}\) | 2.8000 \(10^{-10}\) |
| 1    | 1.481745733 \(10^{-6}\) | 1.6510 \(10^{-8}\) | 2.469575668 \(10^{-6}\) | 2.7400 \(10^{-8}\) |
| 2    | 1.481410254 \(10^{-6}\) | 3.3120 \(10^{-8}\) | 2.469017002 \(10^{-6}\) | 5.5100 \(10^{-8}\) |
| 3    | 1.480852273 \(10^{-6}\) | 4.9740 \(10^{-8}\) | 2.468086083 \(10^{-6}\) | 8.2770 \(10^{-8}\) |
| 4    | 1.480747008 \(10^{-6}\) | 6.6370 \(10^{-8}\) | 2.466788188 \(10^{-6}\) | 1.1047 \(10^{-7}\) |
| 5    | 1.479051719 \(10^{-6}\) | 8.2290 \(10^{-8}\) | 2.465126777 \(10^{-6}\) | 1.3820 \(10^{-7}\) |
Figure 1. Comparison of bright soliton and approximate solutions in case (1) when $a = 5$ and $b = 10$.

Figure 2. Comparison of bright soliton and approximate solutions in case (1) when $a = 5$ and $b = 10$.

Figure 3. 3D surface of the bright soliton solution of CLL equation via ADM in case (1).
Case (2). Consider the negative-signed solution \((-\cdot)\) given by

\[ u(x, t) = \sqrt{\gamma - \eta \tanh[\lambda(x - \nu t)]} e^{(i\chi - \omega t + \theta(x - \nu t))}. \]

Table 2. Absolute error presentation for \(\psi\)-shaped soliton when \(a = 5\) and \(b = 10\).

| \(x\)  | Error ADM \(t = 0.3\) | Error IADM \(t = 0.3\) | Error ADM \(t = 0.5\) | Error IADM \(t = 0.5\) |
|-------|-------------------------|-------------------------|-------------------------|-------------------------|
| \(-5\) | 3.916242087 \(10^{-6}\) | 4.5869 \(10^{-7}\)     | 6.527069524 \(10^{-6}\) | 7.6958 \(10^{-7}\)     |
| \(-4\) | 3.914265546 \(10^{-6}\) | 3.6798 \(10^{-7}\)     | 6.523778129 \(10^{-6}\) | 6.1838 \(10^{-7}\)     |
| \(-3\) | 3.912731721 \(10^{-6}\) | 2.7717 \(10^{-7}\)     | 6.521220382 \(10^{-6}\) | 4.6706 \(10^{-7}\)     |
| \(-2\) | 3.91163022 \(10^{-6}\)  | 1.8635 \(10^{-7}\)     | 6.5193874 \(10^{-6}\)   | 3.1567 \(10^{-7}\)     |
| \(-1\) | 3.91074263 \(10^{-6}\)  | 9.5480 \(10^{-8}\)     | 6.5182903 \(10^{-6}\)   | 1.6423 \(10^{-7}\)     |
| 0     | 3.910754848 \(10^{-6}\) | 4.5800 \(10^{-9}\)     | 6.5179247 \(10^{-6}\)   | 1.2730 \(10^{-8}\)     |
| 1     | 3.910974429 \(10^{-6}\) | 8.6310 \(10^{-8}\)     | 6.518290298 \(10^{-6}\) | 1.3875 \(10^{-7}\)     |
| 2     | 3.911632599 \(10^{-6}\) | 1.7719 \(10^{-7}\)     | 6.519386983 \(10^{-6}\) | 2.9019 \(10^{-7}\)     |
| 3     | 3.912728386 \(10^{-6}\) | 2.6802 \(10^{-7}\)     | 6.521216573 \(10^{-6}\) | 4.4161 \(10^{-7}\)     |
| 4     | 3.914265560 \(10^{-6}\) | 3.5881 \(10^{-7}\)     | 6.523776175 \(10^{-6}\) | 5.9292 \(10^{-7}\)     |
| 5     | 3.916237412 \(10^{-6}\) | 4.4952 \(10^{-7}\)     | 6.527061714 \(10^{-6}\) | 7.4411 \(10^{-7}\)     |
Figure 5. Comparison of w-shaped soliton and approximate solutions in case (2) when \( a = 5 \) and \( b = 10 \).

Figure 6. Comparison of w-shaped soliton and approximate solutions in case (2) when \( a = 5 \) and \( b = 10 \).

Figure 7. 3D surface of the w-shaped soliton solution of CLL equation via ADM in case (2).
5. Conclusion

In conclusion, the present paper examines numerically the w-shaped soliton solution of the CLL equation by proposing two recursive schemes. The schemes are based on the Adomian’s efficient decomposition technique for treating differential equations. We successfully derived two numerical iterative schemes using the ADM and IADM for the CLL equation and further simulated with the aid of Maple software for error analysis. It is noted from both the table and figures that the IADM performs better than the ADM using different time levels; which is in conformity with most of the results obtainable in the literature. We thus recommend the proposed schemes for investigating different evolution and Schrödinger equations numerically whenever less number of iterations and minimum errors are aimed at.

ORCID iDs

ASHF Mohammed https://orcid.org/0000-0003-0137-1914

References

[1] Wazwaz A M 2010 Partial Differential Equations and Solitary Waves Theory. (Berlin: Springer Science & Business Media) May 28
[2] Kivshar Y S and Agrawal G P 2003 Optical Solitons: From Fibers to Photonic Crystals. (Academic press) Jun 12
[3] Ruderman M S 2002 DNLS equation for large-amplitude solitons propagating in an arbitrary direction in a high-β Hall plasma J. Plasma Phys. 67 271–6
[4] Xu Z, Li L, Li Z and Zhou G 2003 Modulation instability and solitons on a cw background in an optical fiber with higher-order effects Phys. Rev. E 67 026603
[5] González-Gaxiola O and Biswas A 2018 W-shaped optical solitons of Chen–Lee–Liu equation by Laplace–Adomian decomposition method Opt. Quantum Electron. 50 314
[6] Yang B, Zhang W-G, Zhang H-Q and Pei S-B 2014 Generalized Darboux transformation and rational soliton solutions for Chen–Lee–Liu equation Appl. Math. Comput. 242 863–76
[7] Zhang J, Liu W, Qiu D, Zhang Y, Porsezian K and He J 2015 Rogue wave solutions of a higher-order Chen–Lee–Liu equation Phys. Scr. 90 055207
[8] Kudryashov N A 2019 General solution of the traveling wave reduction for the perturbed Chen–Lee–Liu equation Optik 186 339–49
[9] Triki H, Zhou Q, Moshokoa S P, Ullah M Z, Biswas A and Belic M 2018 Chirped w-shaped optical solitons of Chen–Lee–Liu equation Optik 155 206–12
[10] Triki H, Babatin M and Biswas A 2017 Chirped bright solitons for Chen–Lee–Liu equation in optical fibers and PCF Optik 149 300–3
[11] Triki H et al 2018 Chirped dark and gray solitons for Chen–Lee–Liu equation in optical fibers and PCF Optik 155 329–33
[12] Triki H et al 2018 Chirped singular solitons for Chen–Lee–Liu equation in optical fibers and PCF Optik 157 156–60
[13] Kara A, Biswas A, Zhou Q, Moraru L, Moshokoa S P and Belic M 2018 Conservation laws for optical solitons with Chen–Lee–Liu equation Optik 174 193–8
[14] Jawad A J M, Biswas A, Zhou Q, Alifiras M, Moshokoa S P and Belic M 2019 Chirped singular and combo optical solitons for Chen–Lee–Liu equation with three forms of integration architecture Optik 178 172–7
[15] Kudryashov N A 2019 General solution of the traveling wave reduction for the perturbed Chen–Lee–Liu equation Optik 186 339–49

Figure 8. 3D surface of the w-shaped soliton solution of CLL equation via IADM in case (2).
[16] Rogers C and Chow K W 2012 Localized pulses for the quintic derivative nonlinear Schrödinger equation on a continuous–wave background Phys. Rev. E 86 037601
[17] Bakodah H, Qarni A A, Banaja M, Zhou Q, Moshokoa S P and Biswas A 2017 Bright and dark Thirring optical solitons with improved adomian decomposition method Optik 130 1115–23
[18] Banaja M, Qarni A, Bakodah H, Zhou Q, Moshokoa S P and Biswas A 2017 The investigate of optical solitons in cascaded system by improved adomian decomposition scheme Optik 130 1107–14
[19] Mohammed A S H F, Bakodah H O and Banaja M A 2019 Approximate Adomian solutions to the bright optical solitary waves of the Chen-Lee-Liu equation MATTER: International Journal of Science and Technology, 5 110–20
[20] Ahmed I, Seadawy A R and Lu D 2019 M–shaped rational solitons and their interaction with kink waves in the Fokas–Lenells equation Phys. Scr. 94 055205
[21] Arshad M, Lu D, Rehman M–U, Ahmed I and Sultan A M 2019 Optical solitary wave and elliptic function solutions of the Fokas–Lenells equation in the presence of perturbation terms and its modulation instability Phys. Scr. 94 105202
[22] Arshad M, Seadawy A, Lu D and Wang J 2017 Travelling wave solutions of Drinfel’d–Sokolov–Wilson, Whitham–Broer–Kaup and (2 1)-dimensional Broer–Kaup–Kupershmit equations and their applications Chin. J. Phys. 55 780–97
[23] Chen H H, Lee Y C and Liu C S 1979 Integrability of nonlinear Hamiltonian systems by Inverse Scattering method Phys. Scr. 20 190–2
[24] Wazwaz A-M 2000 A new algorithm for calculating adomian polynomials for nonlinear operators Appl. Math. Comput. 111 33–51
[25] Qarni A A A, Banaja M A, Bakodah H O, Alshaery A A, Majid F B and Biswas A 2016 Optical solitons in Birefringent fibre: a numerical study Journal of Computational and Theoretical Nanoscience. 13 9001–13
[26] Mohammed A S H F et al 2019 Bright optical solitons of Chen–Lee–Liu equation with improved Adomian decomposition method Optik 181 964–70
[27] Wazwaz A-M 1999 A reliable modification of Adomian decomposition method Appl. Math. Comput. 102 77–86
[28] Wazwaz A-M and El–Sayed SM 2001 A new modification of the Adomian decomposition method for linear and nonlinear operators Appl. Math. Comput. 122 393–405
[29] Mohammed A S H F and Bakodah H O 2020 A reliable modification method for Chen–Lee–Liu equation with different optical solitons Nonlinear Analysis and Differential Equations. 8 67–75
[30] Mohammed A S H F and Bakodah O H 2020 Numerical consideration of Chen–Lee–Liu equation through modification method for various types of solitons American Journal of Computational Mathematics. 10 398–409
[31] Raza N, Afzal U, Butt A R and Rezazadeh H 2019 Optical solitons in nematic liquid crystals with Kerr and parabolic law nonlinearities Opt. Quantum Electron. 51 107
[32] Javidi M and Golbabai A 2008 Exact and numerical solitary wave solutions of generalized Zakharov equation by the variational iteration method Chaos, Solitons & Fractals. 36 309–13
[33] Nuruddeen R I, Muhammad L, Nass A M and Sulaiman T A 2018 A review of the integral transforms–based decomposition methods and their applications in solving nonlinear PDEs Palestine Journal of Mathematics. Jan 1 262–80
[34] Liu J–G, Eslami M, Rezazadeh H and Mirzazadeh M 2020 The dynamical behavior of mixed type lump solutions on the (3 1)-dimensional generalized Kadomtsev–Petviashvili–Boussinesq equation International Journal of Nonlinear Sciences and Numerical Simulation 21 661–5
[35] Savaissou N, Gambo B, Rezazadeh H, Bekir A and Doka S Y 2020 Exact optical solitons to the perturbed nonlinear Schrödinger equation with dual–power law of nonlinearity Opt. Quantum Electron. 52 526–34
[36] Park C et al 2020 Dynamical analysis of the nonlinear complex fractional emerging telecommunication model with higher–order dispersive cubic–quintic Alexandria Engineering Journal. 59 1425–33
[37] Biazar J, Babolian E, Kernber G, Nouri A and Islam R 2003 An alternate algorithm for computing Adomian polynomials in special cases Appl. Math. Comput. 138 523–9