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Research Article

Non-topological Soliton Solution of (2+1)-dimensional Complex Three Coupled Nonlinear Maccari's Model via Modified New Kudryashov Scheme

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Abstract

This paper, deals with the (2+1)-dimensional complex three coupled nonlinear Maccari's model (3-CCME) by utilizing recently presented modified new Kudryashov method (mNKM). The focus of this article is to obtain non-topological soliton solution of 3-CCME by applying mKNM method, which has not been applied before to the investigated problem. Applying the proposed method successfully, besides the non-topological soliton solution of the investigated problem, the breather-like type soliton solution was also obtained and the obtained results are depicted by the 3D, 2D and contour graphical presentations.

Keywords: Complex three coupled nonlinear Maccari's model; Modified new Kudryashov scheme; Soliton solution.

(2+1)-boyutlu Kompleks Lineer Olmayan Üç Bağlı Maccari Modelinin Modifiye Edilmiş Yeni Kudryashov Yöntemi ile Topolojik Olmayan Soliton Çözümü

Öz

Bu makale, yakın zamanda sunulan modifiye edilmiş yeni Kudryashov yöntemini (mNKM) kullanarak (2+1)-boyutlu kompleks lineer olmayan üç bağlı Maccari modelini (3-CCME) ele almaktadır. Bu makalenin amacı, araştırılan probleme daha önce uygulanmamış olan mKNM yöntemini uygulayarak 3-CCME probleminin topolojik olmayan soliton çözümünü elde etmektir. Önerilen yöntem başarılı bir şekilde uygulanarak, incelenen problemin topolojik olmayan soliton çözümünün yanı sıra, breather benzeri türünde soliton çözümü de elde edilmiş ve elde edilen sonuçlar 3D, 2D ve kontur grafik sunumları ile gösterilmiştir.

Anahtar Kelimeler: Kompleks lineer olmayan üç bağlı Maccari modeli; Modifiye edilmiş yeni Kudryashov yöntemi; Soliton çözümü.

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1. Introduction

In the last quarter century, especially depending on the developments in electronics, computers and software, many symbolic software algorithms and packages have been developed. With the effective use of these, many researchers have introduced plethora of algorithms and methods for differential equations, nonlinear partial differential equations and nonlinear fractional differential equations. Some methods are, generalized tanh function [1], modified simple equation [2], auxiliary equation [3], a new Riccati equation rational expansion [4], variable separated ODE [5], enhanced modified tanh expansion [6], generalized Kudryashov [7], extended Kudryashov [8], Jacobi elliptical function [9], extended sinh-Gordon equation expansion [10], and many more. Moreover, these research and developments have also led to the emergence of some special and important new fields of study. Such as optics, optical soliton dynamics in fiber, optoelectronics etc [11-17].

The (2+1)-dimensional complex three-coupled nonlinear Maccari's model reads [18-20]:

$$\begin{cases} iU_t + U_{xx} + UR = 0, & (1.1)\\ iV_t + V_{xx} + VR = 0, & (1.2)\\ iW_t + W_{xx} + WR = 0, & (1.3)\\ R_t + R_y + \left(\left|U+V+W\right|^2\right)_x = 0. & (1.4)\end{cases}$$

In eq. (1) $U(x,y,t), V(x,y,t), W(x,y,t)$ stand for complex, $R(x,y,t)$ represents the real scalar fields, respectively. i is complex unit ($i^2=-1$), x, y are the independent space variables and t denotes the time. Eq. (1) is the simple form of the two-dimensional KdV equation and it is an important equation used to describe isolated wave motion concentrated in a small region of space and is widely used in many fields such as hydrodynamics, optics, plasma, and quantum physics and so on. Moreover, eq. (1) is a type of nonlinear Schrödinger equation (NLSE), so it has been used by researchers and many solutions have been derived with different methods [18-23].

In this study, different from the literature, it is aimed to obtain the exact soliton solution by using the recently presented modified new Kudryashov scheme [24-26].

The study covers the following parts: Mathematical analysis and nonlinear ordinary differential equation (NLODE) form of the 3-CCME obtained in section 2. In section 3, the simple new Kudryashov scheme and implementation to the 3-CCME is presented. In section 4, the obtained solutions and some graphics are presented. In section 5 which is the last part, some concluding remarks are given.

2. NLODE Form and Constraint Equation of 3-CCME:

To get the soliton solutions of 3-CCME in eq. (1), we construct the complex wave transformations as follow:

$$\begin{cases} U = U(x,y,t) = e^{i*\theta}u(x,y,t) = e^{i*\theta}u(\xi),\\ V = V(x,y,t) = e^{i*\theta}v(x,y,t) = e^{i*\theta}v(\xi),\\ W = W(x,y,t) = e^{i*\theta}w(x,y,t) = e^{i*\theta}w(\xi),\\ R = R(x,y,t) = R(\xi), \end{cases} \quad (2)$$

$$\theta = \alpha x + \beta y + r t, \quad \xi = x + y + \omega t, \quad (3)$$

in which α, β, r, ω are the arbitrary real values to be calculated. Considering the eqs. (1), (2) and (3) together, we derive:

$$\begin{cases} u'' + i(2\alpha+\omega)u' - (r+\alpha^2)u + uR = 0, & (4.1)\\ v'' + i(2\alpha+\omega)v' - (r+\alpha^2)v + vR = 0, & (4.2)\\ w'' + i(2\alpha+\omega)w' - (r+\alpha^2)w + wR = 0, & (4.3)\\ (\omega+1)R' + 2(u+v+w)(u'+v'+w') = 0. & (4.4)\end{cases}$$

In eq. (4) superscript $'$ shows the $d/d\xi$. Integrate the eq. (4.4) once and take into account the integration constant zero, the result is,

$$R = -\frac{(u+v+w)^2}{\omega+1}. \quad (5)$$

Plugging the eq. (5) into eqs. (4.1) -(4.3) we derive,

$$u'' + i(2\alpha+\omega)u' - (r+\alpha^2)u - u\frac{(u+v+w)^2}{\omega+1} = 0, \quad (6.1)$$

$$v'' + i(2\alpha+\omega)v' - (r+\alpha^2)v - v\frac{(u+v+w)^2}{\omega+1} = 0, \quad (6.2)$$

$$w'' + i(2\alpha+\omega)w' - (r+\alpha^2)w - w\frac{(u+v+w)^2}{\omega+1} = 0. \quad (6.3)$$

To obtain the soliton solution of eq. (6), we accept the following simple definitions:

$$v = \mu_1 u, \quad w = \mu_2 u, \quad (7)$$

where μ_1 and μ_2 are non-zero arbitrary values. Combination of the eqs. (5), (6) and (7), gives:

$$R = -\frac{(1+\mu_1+\mu_2)^2 u^2}{\omega+1}, \quad (8)$$

$$u'' + i(2\alpha+\omega)u' - (r+\alpha^2)u - \frac{(1+\mu_1+\mu_2)^2}{\omega+1}u^3 = 0 \quad (9.1)$$

$$v'' + i(2\alpha+\omega)v' - (r+\alpha^2)v - \frac{(1+\mu_1+\mu_2)^2}{(\mu_1\mu_2)^2(\omega+1)}v^3 = 0 \quad (9.2)$$

$$w'' + i(2\alpha+\omega)w' - (r+\alpha^2)w - \frac{(1+\mu_1+\mu_2)^2}{(\mu_1\mu_2)^2(\omega+1)}w^3 = 0 \quad (9.3)$$

Let us consider eq. (9.1) and equate its real and imaginary parts separately to zero,

$$2\alpha+\omega=0 \tag{10}$$

$$u''-(\alpha^2+r)u-\frac{(1+\mu_1+\mu_2)^2}{\omega+1}u^3=0 \tag{11}$$

Eq. (10) yields

$$\omega=-2\alpha, \tag{12}$$

and eq. (11) is the NLODE form of the eq. (1) under the following structure:

$$\begin{aligned}(\omega+1)\left(\alpha^2+r\right)u(\xi)+(1+\mu_1+\mu_2)^2\left(u(\xi)\right)^3+\\-(\omega+1)u''(\xi)=0\end{aligned} \tag{13}$$

3. The Proposed Simple mNKM and Implementation to 3-CCME

To get the non-topological soliton solution of eq. (1), we propose the solution in the following truncated series form:

$$u(\xi)=\sum_{i=0}^{k}A_i\Omega^i(\xi) \quad , \quad A_k\neq 0, \tag{14}$$

where $A_0,...,A_k$ unknown real values, k is the positive integer balancing constant which is to be obtained by using the balancing rule in eq. (13). If we apply the balancing rule between the terms $u''(\xi)$, $\left(u(\xi)\right)^3$ in eq. (13), results, $k=1$. So, eq. (14) turns into following form:

$$u(\xi)=A_0+A_1\Omega(\xi) \quad , \quad A_1\neq 0, \tag{15}$$

where $\Omega(\xi)$ satisfies the following differential equation,

$$\left(\frac{d\Omega(\xi)}{d\xi}\right)^2=\sqrt{ln(H)^2\,\Omega(\xi)^2\left(1-\lambda\Omega(\xi)^2\right)} \quad , \tag{16}$$

$$0<H\neq 1.$$

The eq. (16) has the solution,

$$\Omega(\xi)=\frac{2L}{L^2H^{\xi}+\lambda H^{-\xi}}, \tag{17}$$

where λ, L are non-zero arbitrary real values. Inserting the eqs. (15) and (16) into eq. (13), we derive the polynomial form in power of $\Omega(\xi)$. Considering the all coefficients of the $\Omega^i(\xi)$, ($i=0,1,2,3$) as zero we achieve the following algebraic system:

$$\Omega^0(\xi)=-A_0\left(-(1+\mu_1+\mu_2)^2A_0^2+\left(\alpha^2+r\right)(2\alpha-1)\right)=0,$$

$$\Omega^1(\xi)=-A_1\left((-2\alpha+1)(\ln(H))^2-3(1+\mu_1+\mu_2)^2A_0^2+\left(\alpha^2+r\right)(2\alpha-1)\right)=0,$$

$$\Omega^2(\xi)=3A_0A_1^2\left(1+\mu_1+\mu_2\right)^2=0, \tag{18}$$

$$\Omega^3(\xi)=-\left(2\lambda(2\alpha-1)(\ln(H))^2-A_1^2\left(1+\mu_1+\mu_2\right)^2\right)A_1=0.$$

Eq. (18) produces the following possible solution sets,

$$\text{Set}_1=\{r=(\ln(H))^2-\alpha^2,\lambda=\frac{A_1^2\left((\mu_1+\mu_2)^2+2\mu_1+2\mu_2+1\right)}{2(\ln(H))^2(2\alpha-1)},A_0=0,A_1=A_1\},$$

$$\text{Set}_{2,3}=\{\alpha=\sqrt{(\ln(H))^2-r},A_0=0,A_1=\mp\frac{\ln(H)\sqrt{-2\lambda+4\sqrt{\lambda^2(\ln(H))^2-\lambda^2r}}}{1+\mu_1+\mu_2}\},$$

(19)

$$\text{Set}_{4,5}=\{\alpha=-\sqrt{(\ln(H))^2-r},A_0=0,A_1=\mp\frac{\ln(H)\sqrt{-2\lambda-4\sqrt{\lambda^2(\ln(H))^2-\lambda^2r}}}{1+\mu_1+\mu_2}\},$$

$$\text{Set}_{6,7}=\{r=(\ln(H))^2-\alpha^2,A_0=0,A_1=\mp\frac{\ln(H)\sqrt{\lambda(4\alpha-2)}}{1+\mu_1+\mu_2}\}.$$

If we substitute the Set_1 into eq. (15) by combine the eqs. (2), (3), (8) and (12) together, result is the soliton solution of eq. (1) as follows:

$$U(x,y,t)=\frac{2A_1Le^{i\left(\alpha x+\beta y+\left((ln(H))^2-\alpha^2\right)t\right)}}{L^2H^{x+y-2\alpha t}+\Theta}, \tag{20}$$

$$V(x,y,t)=\mu_1\frac{2A_1Le^{i\left(\alpha x+\beta y+\left((ln(H))^2-\alpha^2\right)t\right)}}{L^2H^{x+y-2\alpha t}+\Theta}, \tag{21}$$

$$W(x,y,t)=\mu_2\frac{2A_1Le^{i\left(\alpha x+\beta y+\left((ln(H))^2-\alpha^2\right)t\right)}}{L^2H^{x+y-2\alpha t}+\Theta}, \tag{22}$$

$$\begin{aligned}R(x,y,t)=-\frac{4A_1^2L^2}{1-2\alpha}(\frac{1}{L^2H^{x+y-2\alpha t}+\Theta}+\\+\mu_1\frac{1}{L^2H^{x+y-2\alpha t}+\Theta}+\mu_2\frac{1}{L^2H^{x+y-2\alpha t}+\Theta})^2.\end{aligned} \tag{23}$$

where

$$\Theta=\frac{A_1^2\left((\mu_1+\mu_2)^2+2\mu_1+2\mu_2+1\right)H^{2\alpha t-x-y}}{2(ln(H))^2(2\alpha-1)},\alpha\neq\frac{1}{2}.$$

Remark: One can get the other soliton solution functions easily by substituting the Set_i ($i=2,...,7$) into eq. (15) by combining the eqs. (2), (3), (8) and (12) together. Therefore, in order not to take up too much volume in the article, only the function for Set_1 is given and a graphically presented. Besides, the functions obtained by using other solution sets will also give the same type of soliton solution.

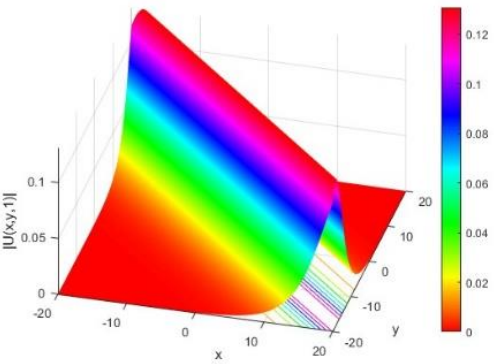
4. Results and Discussion

Let us consider the eqs. (20), (21), (22) and (23) for presenting the some graphical representations.

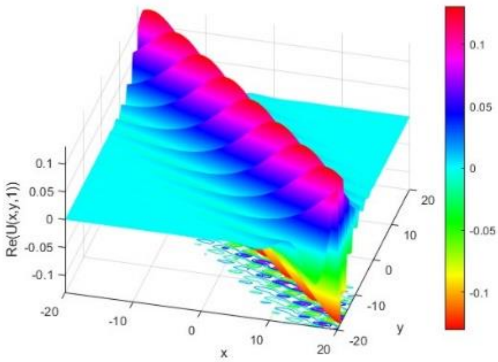
In fig. 1, we depict various plots of investigated problem. Fig. 1-a represents 3D $|U(x,y.t)|$, fig. 1-b 3D $Re(U(x,y.t))$, fig. 1-c 3D $Im(U(x,y.t))$, fig. 1-d contour $|U(x,y.t)|$, fig. 1-e contour $Re(U(x,y.t))$, fig. 1-e contour $Im(U(x,y.t))$, fig. 1-g 2D $|U(x,y.t)|$, fig. 1-h 2D $Re(U(x,y.t))$ and fig. 1-i 2D $Im(U(x,y.t))$ components of $U(x,y.t)$ in eq. (20), respectively. It is selected Set_1 and $H=0.75,\ A_1=1.2,\ \mu_1=0.5,\ \mu_2=0.7,\ \alpha=0.75,\ \beta=2.$ The fig. 1-a, 1-d and 1-g represent non-topological soliton solution of $U(x,y.t)$ in eq. (20). The other sub-graphics of fig. 1 demonstrate the breather-like soliton. Moreover, figs. 1-g, 1-h and 1-i indicate the traveling wave property of $U(x,y.t)$ for $t=1,2$ *and* $3.$

Remark: Since it is defined as $v=\mu_1 u,\ w=\mu_2 u,$ in eq. (7), the graphs of *V(x,y,t)* and *W(x,y,t)* will have the same shape as the multiplication of μ_1 and μ_2, respectively, for the amplitudes of the graphs given by fig. 1. But since they will have the same form, they have not been plotted separately.

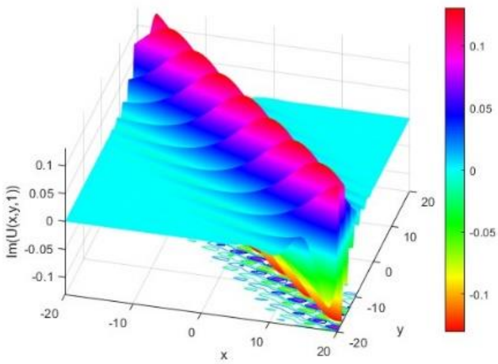
Fig. 2 shows the wave dynamic of the $R(x,y.t)$ solution in eq. (23) for $H=0.75,\ A_1=1.2,\ \mu_1=0.5,\ \mu_2=0.7,\ \alpha=0.75,$ $\beta=2$ and Set_1. Fig. 2-a for 3D, fig. 2-b for contour and fig. 2-c for 2D view of $R(x,y.t)$. The fig. 2 depicts non-topological soliton solution of $R(x,y.t)$ in eq. (23). Also, we can see the traveling wave property of $R(x,y.t)$ for $t=1,2$ *and* 3 in fig. 2-c.



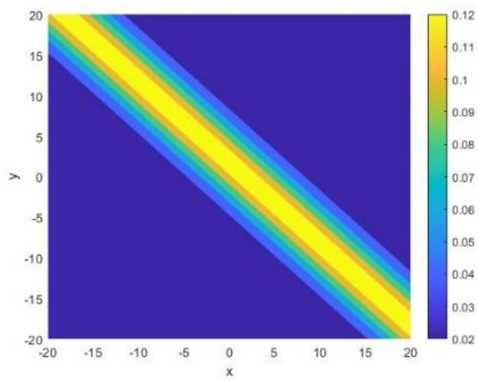
(a) 3D view of $|U(x,y.t)|$



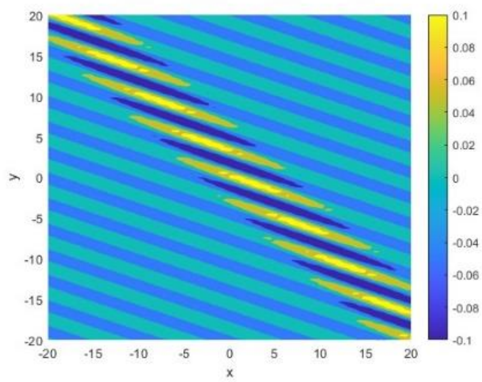
(b) 3D view of $Re(U(x,y.t))$



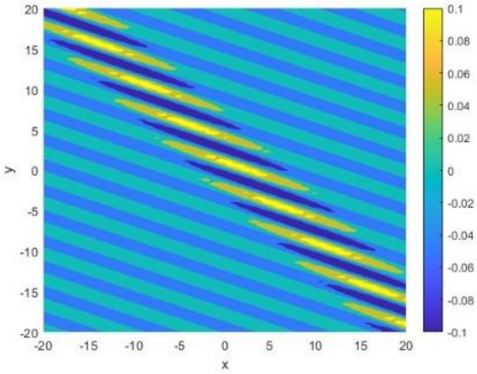
(c) 3D view of $Im(U(x,y.t))$



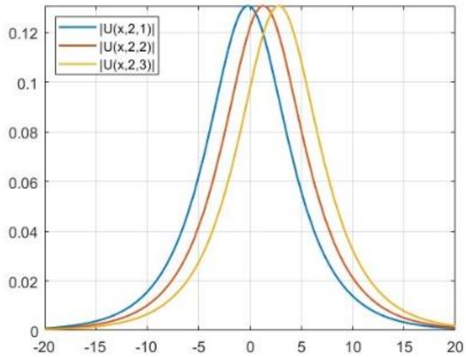
(d) contour of $|U(x,y.t)|$



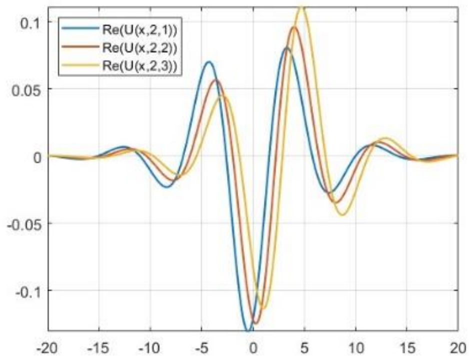
(e) contour of $Re(U(x,y.t))$



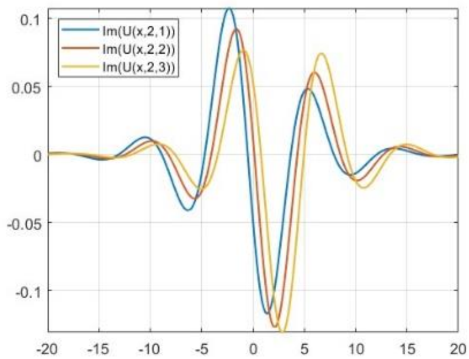
(f) contour of $Im(U(x,y.t))$



(g) 2D view of $|U(x,y.t)|$

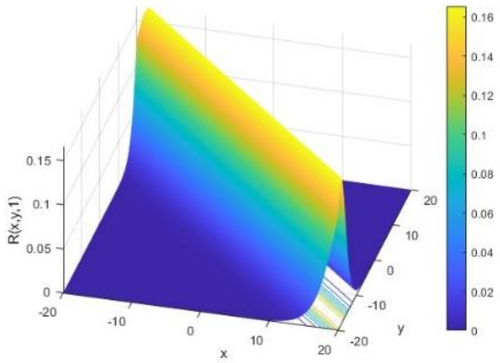


(h) 2D view of $Re(U(x,y.t))$

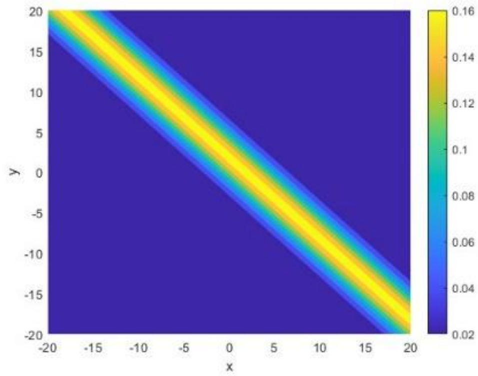


(i) 2D view of $Im(U(x,y.t))$

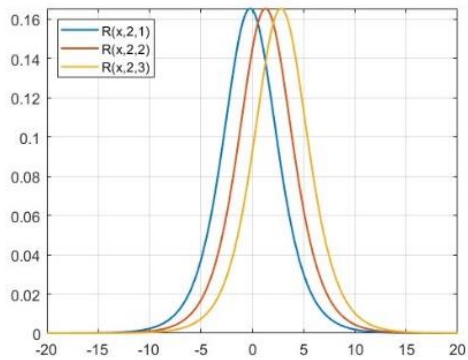
Figure 1 The various plots of $U(x,y,t)$ in eq. (20) by selecting Set_1 in eq. (19) and $L=10,\ H=0.75,\ A_1=1.2,\ \mu_1=0.5,$ $\mu_2=0.7, \alpha=0.75,\ \beta=2.$ (in fig. (g-i), $t=1,2\ and\ 3$)



(a) 3D view of $R(x,y.t)$



(b) contour of $R(x,y.t)$



(c) 2D view of $R(x,y.t)$

Figure 2 The various plots of $R(x,y,t)$ in eq. (23) by selecting Set_1 in eq. (19) and $L=10,\ H=0.75,\ A_1=1.2,\ \mu_1=0.5,$ $\mu_2=0.7, \alpha=0.75,\ \beta=2.$

5. Conclusion

In this research article, in order to obtain non-topological soliton solution of 3-CCME, we proposed and successfully implemented recently presented modified new Kudryashov method for the first time in this article. We derived not only non-topological soliton solution but also breather-like soliton solution from the real and imaginary parts of 3-CCME. The obtained results imply that the modified new Kudryashov method is easily applicable, an effective, efficient and powerful method for solving such kind of evolution problems.

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