Shape changing solitons in optical system using analytical method

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Abstract

The perturbed Gerdjikov-Ivannov (G-I) equation governs the behavior of solitons in fibre optical system. We derived the solitary wave solutions of the G-I equation by implementingsech-tanh method. This method is very much helpful to construct the many solitary wave solutionssuch as kink/anti-kink, dark solitonic structures for different kinds of nonlinear systems.We investigated the propagation of dark solitons and shape changing antikink solitons along theoptical fibre.

Keywords: Optical soliton, analytical method, Fibre optics

1. Introduction

Optical solitons are produced by the cancellation of the nonlinear dependence of index of refraction upon intensity and the linear chromatic dispersion [1]. Under ideal conditions, soliton pulses can travel over long distances without any distortion. In experiments, solitons are transmitted over long distances of about 10,000 km at a rate 10Gbps or more in a single-channel. When combined with wavelength-division-multiplexing (WBM), where the N channels are transmitted simultaneously, the transoceanic distances has been achieved when soliton transmitted with N10Gbps bit rates. Generally, higher bit rates per channel are allowed in soliton transmission (ashigh as 40-100Gbps over shorter distances) in comparison with other schemes such as non-return to zero (NRZ) transmission. The performance of the fibre optical systems are considerably improved, although these data rates are quite high, there is an demand for increasingly higher speed communications. This paper is mainly focused on the solitary solutions to the perturbed Gerdjikov-Ivannov (G-I) equation using analytical method in section 2. This equation is one ofthe three forms of derivative nonlinear Schrodingers equation and is studied to govern the dynamics of soliton propagation through optical fibers [2-4]. Finally, the conclusion is given in section 3.Consider the perturbed Gerdjikov-Ivanov (G-I) equation, in its dimensionless form, given as [2]

$$iu_t + au_{xx} + b|u|^4u = i\Big[cu^2u_x^* + \alpha u_x + \lambda_1(|u|^2u)_x + \theta(|u|^2)_x u\Big], \qquad (1)$$

where, $u(x,t)$ is a complex function represents the wave profile, the independent variable t and $x$denotes time in dimensionless form and distance along the fiber.

2. Shape changing soliton solutions using sech-tanh method

Many new approaches with advantages on the one hand and disadvantages on the other hand have been suggested to solve various nonlinear equations, such as the variational iteration method [5], the homotopy perturbation method [6], the Jacobi-elliptic function method [7], doubleexp-function method [8], the modified extended tanh-function method [9,10] and others. Ouraim is to obtain traveling wave solutions of the form:

$$u(x,t) = u(\xi)\ exp\Big[i(px + rt + \phi)\Big], \quad \xi = x + vt, \qquad (2)$$

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where *v* is the soliton speed, *p* is the soliton frequency, *r* is the soliton wave number and □ is thephase constant. Substituting Eq. (2) into Eq. (1), we obtain the ODE in the following form,

$$u_{\xi\xi}(\xi) - iA_4 u_\xi(\xi) + iA_5 u^2(\xi) u_\xi(\xi) - A_1 u(\xi) - A_2 u^3(\xi) + A_3 u^5(\xi) = 0, \qquad (3)$$

where,

$A_1 = \frac{r}{a} + p^2 - \frac{\alpha p}{a}$, $A_2 = \frac{cp-\lambda_1}{a}$, $A_3 = \frac{b}{a}$, $A_4 = \frac{c}{a} + 2p - \frac{\alpha}{a}$ and $A_5 = \frac{c+3\lambda_1+2\theta}{a}$. Separating real and imaginary parts of the ordinary differential equation (ODE)

$$u_{\xi\xi}(\xi) - A_1 u(\xi) - A_2 u^3(\xi) + A_3 u^5(\xi) = 0, \qquad (4)$$

and

$$-A_4 u_\xi(\xi) + A_5 u^2(\xi) u_\xi(\xi) = 0, \qquad (5)$$

we use the following solutions in series of sech-tanh as [11]

$$u(\xi) = a_0 + \sum_{i=1}^{n} sech^{i-1}\xi(a_i sech\xi + b_i tanh\xi) \qquad (6)$$

where, $a_0, a_1, \ldots a_n, b_1, \ldots b_n$ solitary constants. Balancing the highest-order nonlinear term and highest-order linear partial derivative term in Eq. (3), which yields the value of $n = 1$. The solution of Eq. (3) takes the form

$$u(\xi) = a_0 + a_1 sech(\xi) + b_1 tanh(\xi), \qquad (7)$$

where, a_0, a_1 and b_1 are parameters to be found in terms of the other parameters. Substituting Eq. (7) into Eqs. (4 & 5), and collecting the powers of sech(□) tanh(□), subsequently solving the system of equations with the help of Maple, we obtain the values of a_0, a_1 and b_1 as follows,

$$a_0 = \sqrt{\frac{-3A_2}{10A_3}}, \quad a_1 = 0, \quad b_1 = \sqrt{-\left(\frac{A_4}{A_5} + \frac{3A_2}{10A_3}\right)}, \qquad (8)$$

substituting the above equation in Eq. (2), we get

$$u(x,t) = \left[\sqrt{\frac{-3A_2}{10A_3}} + \sqrt{-\left(\frac{A_4}{A_5} + \frac{3A_2}{10A_3}\right)} tanh(\xi)\right] exp\Big[i(px + rt + \phi)\Big]. \qquad (9)$$

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We have plotted the above equation for optical system and obtain the dark solitonic structure with the parameter values p = 0.1,r = 0.01,v = 0.0008,□= 0.2, c = 1,□□ = 0.2,□□ = 0.5,□ = 0:5and b = 1 which is shown in the Fig. (1). By increasing the value of b = 2 the amplitude of the dark solitonic structure is decreased which is depicted in the Fig. (1 b). Further increasing the value of$b$ = 3 the amplitude of the dark solitonic structure decreasing in the bottom region which is shown in the Fig. (1 c). Again increasing the value of b = 5 the bottom region of the dark solitonic structure decreased but there is no change in the upper region of dark solitonic structure which is shown in the Fig. (1 d). This change is obtained till the value b = 100 which is shown in the Fig.(1 e-i) for the parameter values p = 0.1,r = 0.01,v = 0.0008,□ = 0.2, c = 1,□ = 0.2,□ = 0.5 and□ = 0.5. The variations of dark solitonic structure is clearly exhibits in the corresponding contour plots which is shown in the Fig. (1 a-i).

The shape changing anti-kink solitonic structure for the optical systems are obtained by choosing the value of c = 1 with the parameter values p = 0.1,r = 0.01,v = 0.0008,□ = 0.2,b =0.5, □ = 0.2,□ = 0.5 and □ = 0.5 which is shown in the Fig. (2). This anti-kink solitonic structure changes its shape to dark solitonic structure for c = 3 which is shown in the Fig. (2 b). Further, we get the dark solitonic structure for increasing in the value c = 5 with the increasing of its amplitude which is shown in the Fig. (2 c). Again, we obtain the dark solitonic structure with increasing the amplitude of its structure for c = 7 which is shown in the Fig. (2 d). The Fig.(2 e-g) exhibits the dark solitonic structure for c = 9, 15, 50 by choosing the parameter values$p$ = 0.1,r = 0.01,v = 0.0008,□ = 0.2,b =0.5, □ = 0.2,□ = 0.5 and □ = 0.5. For c=80 the darksolitonic structure is slightly changes its shape to anti-kink solitonic structure which is shown inthe Fig. (2 h). Finally, the figure completely exhibits like a anti-kink solitonic structure for c = 500which is shown in the Fig. (i). This change of structure clearly exhibits in the corresponding contour plots which is depicted in the Fig. (2 a-i).

3. Conclusions

We investigated the solitary wave solutions for the Gerdjikov-Ivannov (G-I) equation for optical systems by using the sech-tanh method. In this paper, we studied the influences of thecoefficient of quintic nonlinearity term and the coefficient of perturbative term c which gives the variations in the dark optical solitonic structure and the shape changing property of kink/antikinksolitonic structure.

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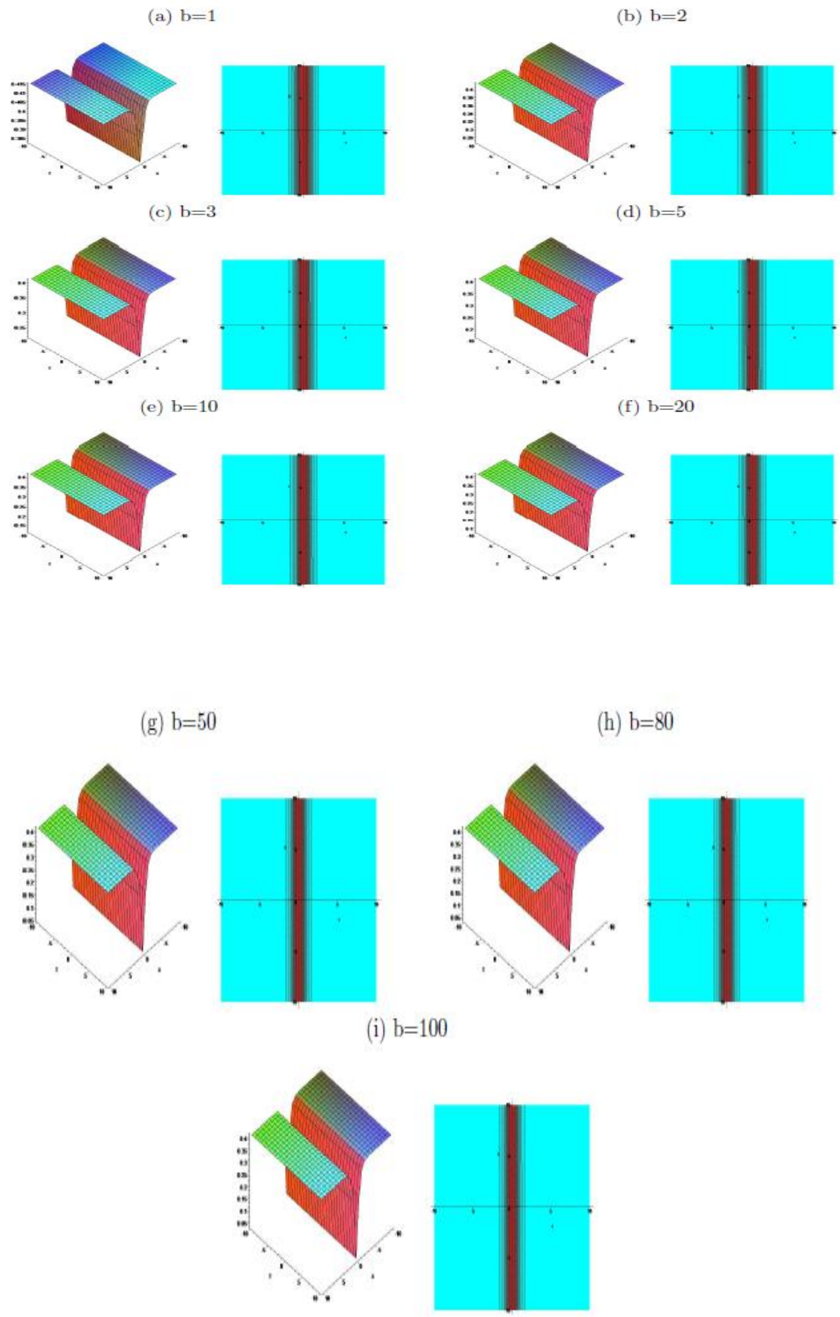

Figure 1: Profile of dark solitons for Eq. (9).

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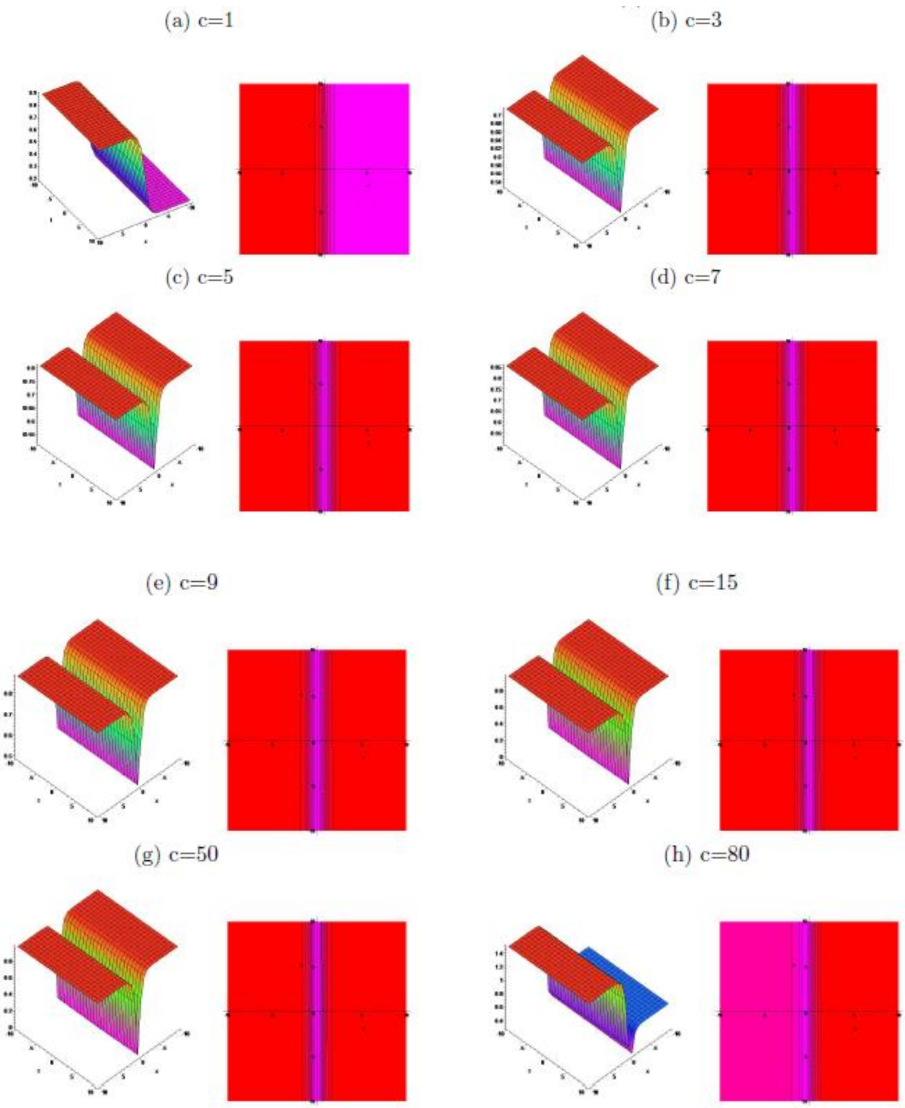

Figure 2: Shape changing anti-kink soliton through dark soliton for Eq. (9).

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