VINAYAKA MISSION'S RESEARCH FOUNDATION
(Deemed to be University under section 3 of the UGC Act 1956)

VMRF(DU) Salem and Siemens Centre of Excellence in Manufacturing, National Institute of Technology, Trichy.

Vinayaka Mission's Research Foundation (Deemed to be University) (VMRF(DU)) in Salem, India, and Siemens Centre of Excellence in Manufacturing, National Institute of Technology, Trichy. have signed Memorandum of Understanding (MoU) held on 23rd August 2021,

Nature of Collaboration

Internships, Utilization of resources in funding/ consultancy proposals, conducting-workshops-symposium- conference, skill development related courses

MOU ACTIVITIES

Visit Report – Siemens Center for Excellence in Manufacturing “National Institute of Technology Tiruchirappalli” (NIT Trichy) Laboratory

Date: - 9/10/2023

As per research work to attend the one of the Government side research laboratory to fulfill one of the criteria and while doing PhD research to learn more with advance technology I found the NIT lab to visit. I planned according to the two have mail concern via NIT Trichy as our University MOU Signed with NIT Trichy. We (Mr. Chandrashekhar Kumar & Dr. PM Murali) got an opportunity of visiting the National Institute of Technology Tiruchirappalli (NIT Trichy) laboratory on [9/10/2023]. The purpose of the visit was to gain insights into the cutting-edge research and technological advancements taking place at one of India's premier engineering institutions related to Robotics Laboratory.

As we know that NIT Trichy, established in 1964, has consistently been ranked among the top engineering institutes in India. It is renowned for its academic excellence, research contributions, and state-of-the-art infrastructure. The institute is committed to fostering innovation and technological advancements and having the “Siemens Center for Excellence in Manufacturing” where learning hands on practical experience from Technical and manufacturing robot aspect.

During the visit, I had the opportunity to explore research laboratories dedicated to diverse fields such as mechanical engineering research laboratory. In this laboratory was equipped with advanced instruments and technologies automobile robots names as Kuka Robots, which is working with Welding and pick and place object and industrial level heavy weight lifting and welding and joining the heavy metal objects showcasing the institute's commitment to providing with a comprehensive learning environment.

“I have found the related to my research objective like to pick and place concept understanding and developing my research idea. In Kuka Robots can have two finger object catching for picking and place and welding functions? When we want to make quick object picking place we need to make 2D to 3D concept to pick and place the objects so I found the idea in this to make easier to make picking and place object with 3 to 5 fingers which can support in all aspects.” Also we got an opportunity to attend NIT Trichy the online workshop Recent Advances in Control and Instrumentation Design Techniques of Robotic Systems 27th to 31st October 2023, 5 days to understand more related robotics mechanical system with AI and Medical support systems.

I plan to revisit the NIT Trichy laboratory to understand the motor and lifting mechanism and its automation concept and working principles. Also, related to the circuit advance concept to understand the advanced MSO equipment and the circuit wave form to make circuit design concepts to enhance my circuit implementation research gap. This can fill my research gap.

I express my gratitude to the faculty and staff (Dr. Duraiselvam sir & Lab Technicians) at NIT Trichy Siemens Center for Excellence in manufacturing laboratory for their warm hospitality and for sharing their knowledge and expertise. This visit has deepened my appreciation for the contributions of NIT Trichy to the field of robotics in engineering and technology.

Here I have attached my ongoing journey visit to NIT Trichy Laboratory documents:-

Lab Technician and Myself Chandrashekhar Kumar

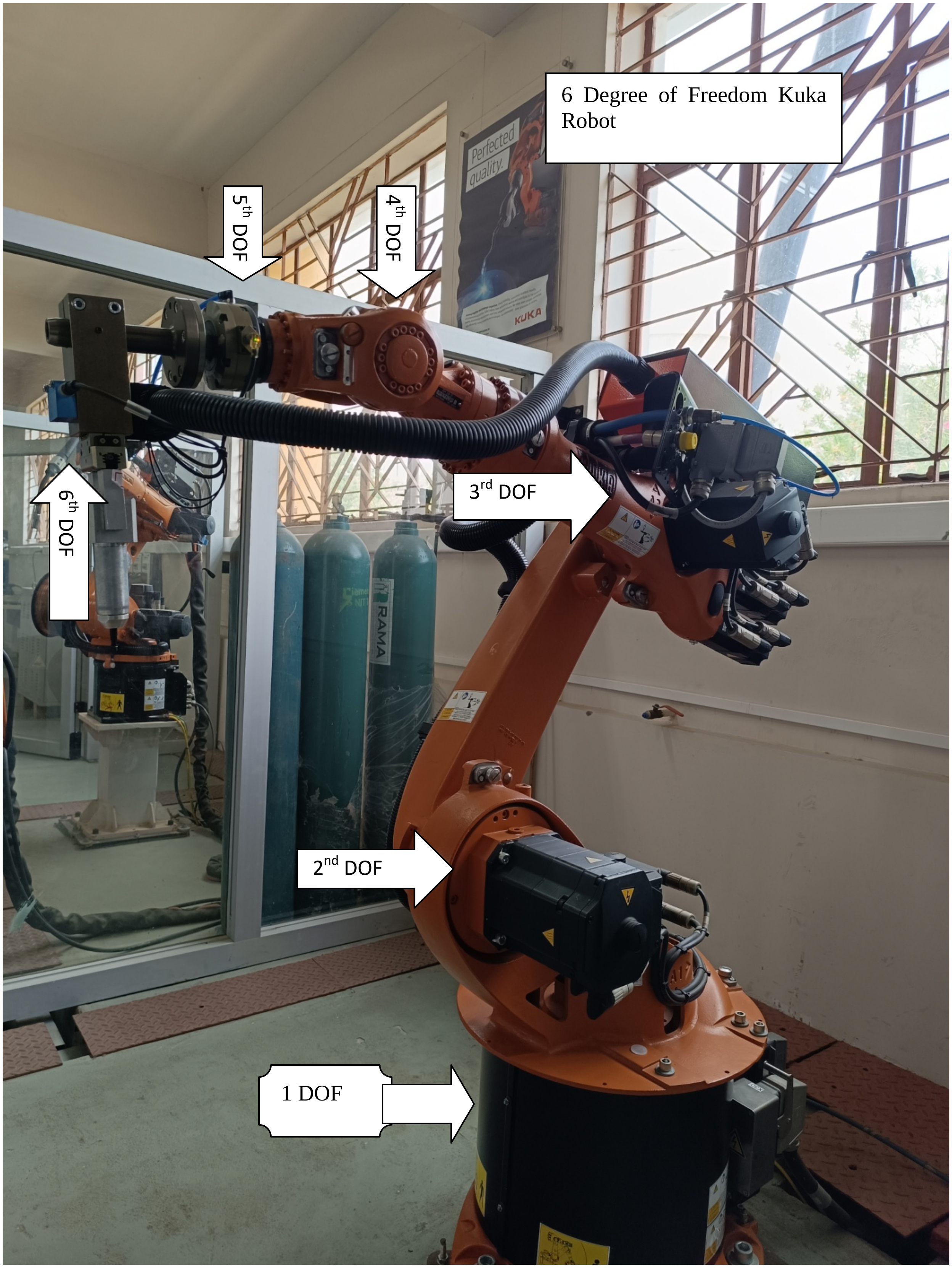
Left-Lab Technician and

Right-Dr. PM Murali Sir

Kuka Robot Software Device to Control the robot

Kuka Robot laser welding and drawing with pick and place


Perfected quality.
KUKA
EMPPI
KempArc


6 Degree of Freedom Kuka Robot
5th DOF
4th DOF
6th DOF
3rd DOF
2nd DOF
1 DOF
Perfected quality.
KUKA
RAMA


Perfected
quality.
KUKA
KEMPPI
KempArc
KUKA
RAMA


KUKA
GPS Map Camera
Thiruverumbur, Tamil Nadu, India
NIT TIRCHY SIEMENS ROBOTIC LAB, QR4C+X3X, Thiruverumbur, Tamil Nadu 620015, India
Lat 10.757355°
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AUTO
MANUAL
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ROBOT
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CONTROL
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GPS Map Camera
Thiruverumbur, Tamil Nadu, India
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Lat 10.757355°
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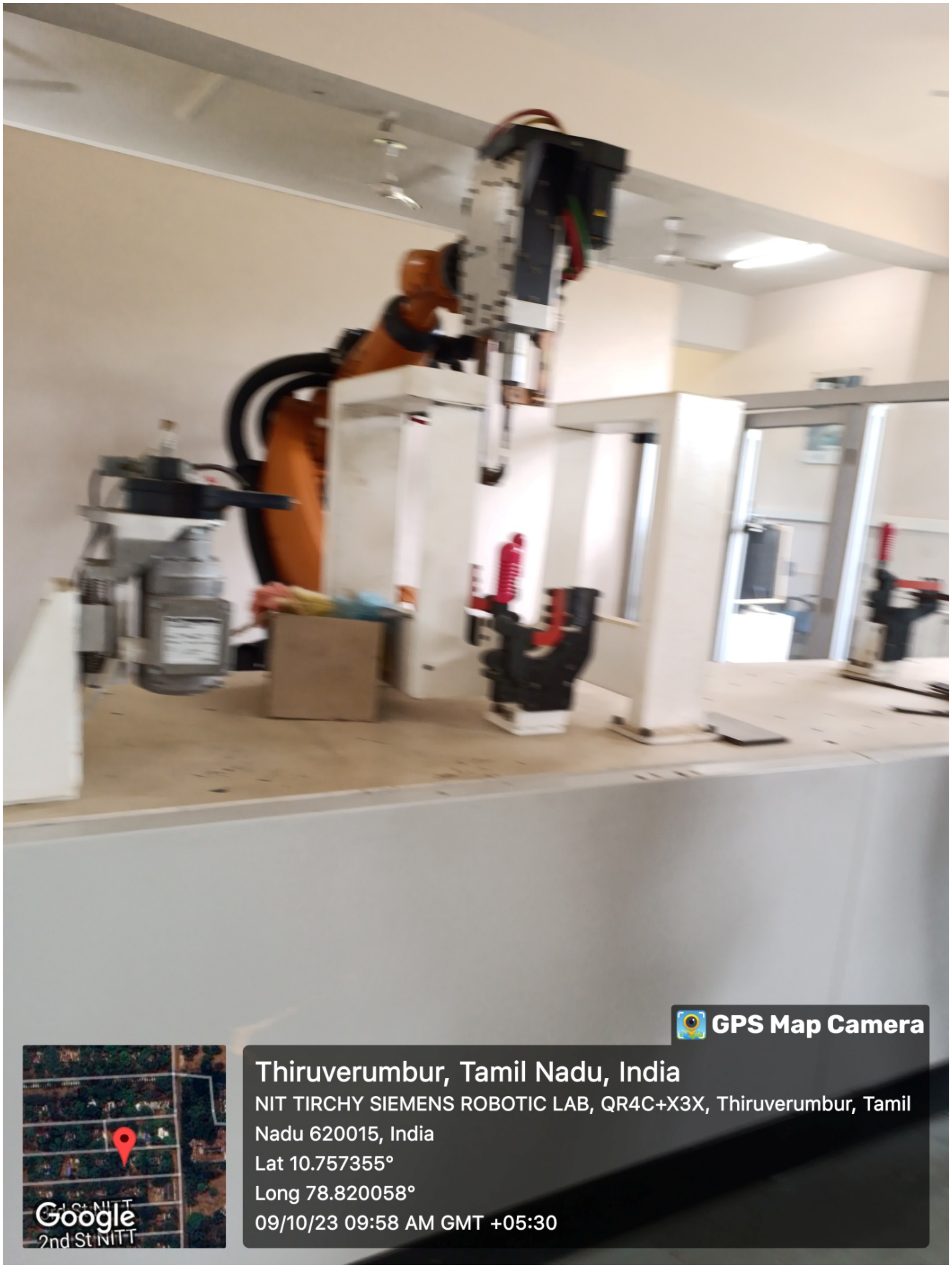
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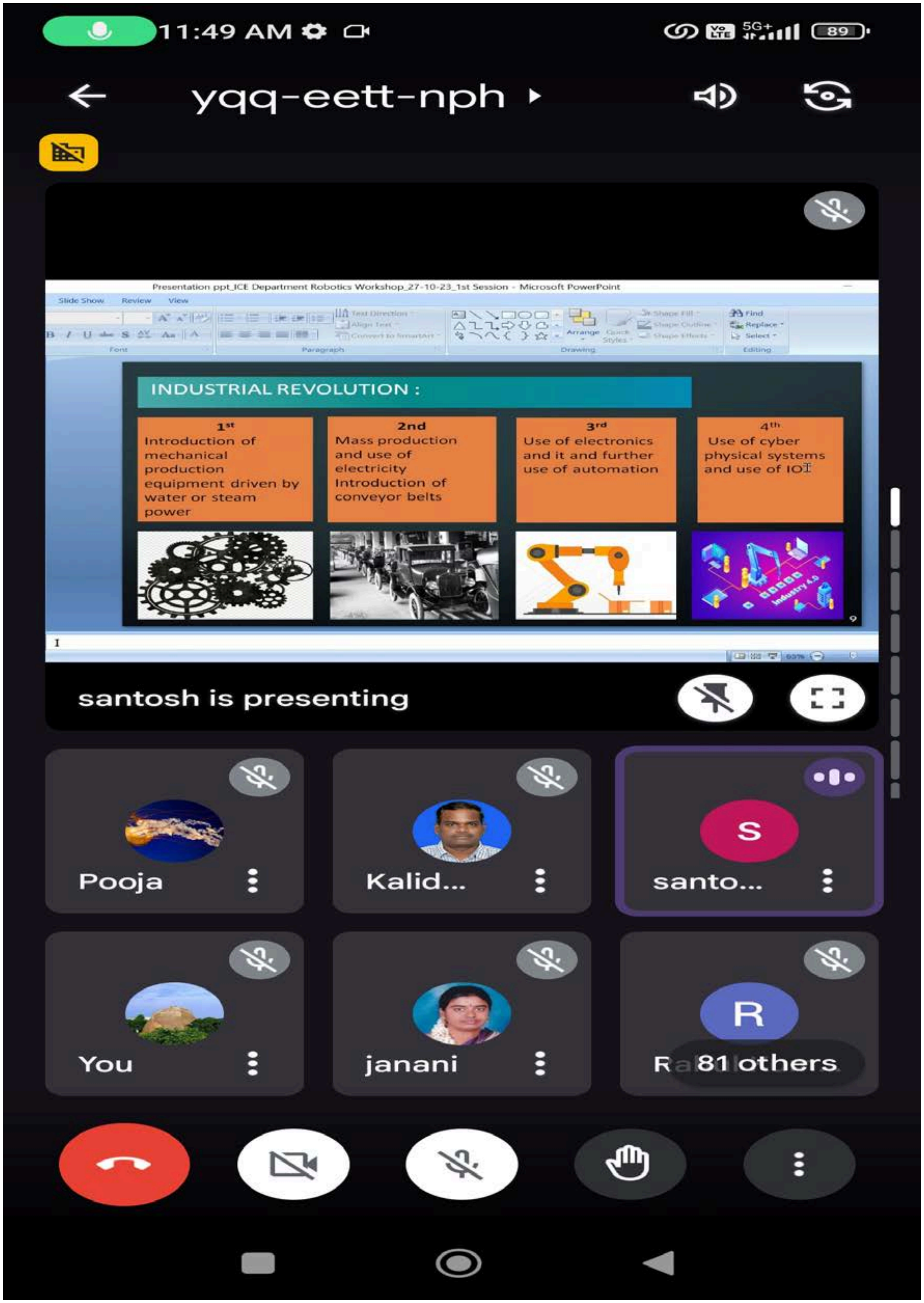
11:49 AM
yqq-eett-nph
Presentation ppt_ICE Department Robotics Workshop_27-10-23_1st Session - Microsoft PowerPoint
INDUSTRIAL REVOLUTION :
1st
Introduction of mechanical production equipment driven by water or steam power
2nd
Mass production and use of electricity Introduction of conveyor belts
3rd
Use of electronics and it and further use of automation
4th
Use of cyber physical systems and use of IOT
santosh is presenting
Pooja
Kalid...
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81 others

Session Details

Title of the session: **Eminent Person Interaction with CSE Faculties By NIT , Trichy**

Date: 21 November 2023

Time : 2.00 Pm to 4.30 PM

Venue: **Annapoorana HiTech Computer Centre, VMKVEC, Salem**

Theme: Internship support for the students and faculty Research Activities funded by Govt.

Expert/Speaker Details:

Dr.A . Santhanavijayan

Assistant Professor

Department of Computer Science and Engineering

National Institute of Technology (NIT) ,

Trichy.

Objectives :

Our resource person and delivered about needs of Research project and how to improve our students internship idea with NIT and other government supports. It gives for the skill enhancement of the training with benefits for the students.

Total no. of Teaching Faculties participated: 20

Total no. of Non-teaching Faculties participated: 03

Resource person interaction with Computer Science and Engineering Faculties for below points :

1. Represented by Research areas and focus on Artificial Intelligence and ML
2. Seed money projects are available with government support of funds in Government Agencies.
3. Faculty members are come and visit SEIMAN lab for the development of Robotic techniques and projects equipment available in NIT , Trichy.
4. NIT provides internship for collaborative institutions and college. Students of Our VMKV Engineering can also apply and utilize this opportunities.
5. Each faculty concentrate on Multidisciplinary research projects with several medical, nursing and physical science also.
6. Motivate Students to do hackathon and smart idea proposal with Central Government scheme and support with each staff as a mentor for some students.
7. Faculty members can apply different research projects with other department members for better do get knowledge commutation with effective output for the society .


GPS Map
Camera Lite
College Office Main, Chinnasiragapadi, Salem, Tamil Nadu 636308, India
Latitude
11.577313°
Longitude
78.0481398°
Local 04:08:18 PM
GMT 10:38:18 AM
Altitude 267 meters
Tuesday, 21.11.2023


GPS Map
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Longitude
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GMT 10:38:40 AM
Altitude 267 meters
Tuesday, 21.11.2023

Report on Research Interaction to the PG students

Dr. Vinothkumar, NIT Trichy

Date: November 25, 2023
Venue: Boash Lab, VMKVEC Campus
Event: Interaction with PG Students of Mechanical Engineering

Introduction:

On November 25, 2023, the Mechanical Engineering Department at VMKVEC was privileged to host Dr. Vinothkumar, a distinguished professor from the esteemed National Institute of Technology, Trichy (NIT Trichy). Dr. Vinothkumar engaged in an insightful interaction with the postgraduate students of Mechanical Engineering at the Boash Lab in our VMKVEC campus.

Session Highlights:

1. Research Experience Sharing:

Dr. Vinothkumar commenced the session by sharing his extensive research experience. He provided valuable insights into the challenges and triumphs he encountered throughout his academic journey. This personal touch resonated well with the students, creating a relatable atmosphere.

2. Thrust Areas of Research:

The distinguished guest took the opportunity to elucidate the thrust areas of research in the field of Mechanical Engineering. He delved into cutting-edge advancements, technological trends, and the significance of exploring new frontiers in research. This not only broadened the students' perspectives but also ignited their curiosity.

3. Motivation for Research Work:

Dr. Vinothkumar, with his inspirational words, motivated the students to actively engage in research work. Emphasizing the importance of contributing to the academic community, he stressed the role of research in shaping the future of Mechanical Engineering. His motivational address aimed to instill a passion for research among the budding engineers.

4. Guidance on Research Grant Opportunities:

An integral part of the session involved Dr. Vinothkumar providing guidance on securing research grants. He shared insights on the avenues available through various central and state government funding agencies. Practical tips and success stories were shared to demystify the application process, encouraging students to pursue financial support for their research endeavors.

Conclusion:

The interaction with Dr. Vinothkumar proved to be a stimulating and enriching experience for the PG students of Mechanical Engineering at VMKVEC. The session not only broadened their academic horizons but also provided practical guidance on navigating the research landscape. This event is a testament to VMKVEC's commitment to fostering a vibrant academic environment by bringing in renowned scholars to engage with students and contribute to their academic and professional growth.

VINAYAKA MISSION'S RESEARCH FOUNDATION
(Deemed to be University under section 3 of the UGC Act 1956)

VINAYAKA MISSION'S KIRUPANANDA VARIYAR ENGINEERING COLLEGE

Internship 2024 at National Institute of Technology, Tiruchirappalli – A Report

Twelve students of Vinayaka Mission's Kirupananda Variyar Engineering College belonging to Department of Biomedical Engineering and Computer Science and Engineeringare undergoing internship at National Institute of Technology, Tiruchirapalli during the period 1 June – 31 July 2024 through a collaborative research MOU with NIT, Tiruchirapalli. Biomedical Engineering students are involved in developing innovative projects like APP-based audiometer, optimized biomedical equipment production processes, enhanced EEG signal processing and Industry 4.0 technologies for biomedical applications. Computer Science and Engineering students are focused in the innovative projects namely predicting potable water quality through deep learning and detecting diabetic retinopathy. These innovative projects provide invaluable hands-on experience, fostering cutting-edge research and strengthening vital academic-industry partnerships.

LIST OF STUDENTS WHO HAVE UNDERGONE INTERNSHIP AT NIT, TIRUCHIRAPALLI during 1 June – 31 July 2024

S. No.	Name of the Student	Year/ Department	Project Title	Guide Name
1	Ilakkia A	IV CSE	Prediction and Classification of Portable Water through Deep Learning	Dr. S. Saroja, Assistant Professor, Department of Computer Applications, NIT, Tiruchirapalli
2	Shanmugapriya C	IV CSE	Prediction and Classification of Portable Water through Deep Learning	Dr. S. Saroja, Assistant Professor, Department of Computer Applications, NIT, Tiruchirapalli
3	Kavinraj V	IV AIDS	Diabetic Retinopathy Detection	Dr. M. Brindha, Associate Professor, Department of Computer Science and Engineering, NIT, Tiruchirapalli
4	Nandhini G	IV AIDS	Diabetic Retinopathy Detection	Dr. M. Brindha, Associate Professor, Department of Computer Science and Engineering, NIT, Tiruchirapalli
5	Sanjay Prasanth M	III BME	Biomedical Signal Processing (EEG)	Dr. P.A. Karthick Assistant Professor Department of Electronics and Instrumentation Engineering, NIT, Tiruchirapalli
6	Venkatesh S	IV BME	APP based audiometer	Dr. R. Periyasamy Assistant Professor, Department of Instrumentation and Control Engineering, NIT, Tiruchirapalli
7	Keerthana S	IV BME	APP based audiometer	Dr. R. Periyasamy Assistant Professor, Department of Instrumentation and Control Engineering, NIT, Tiruchirapalli

8	Hariharan T	IV BME	Biomedical Signal Processing (EEG)	Dr. P.A. Karthick Assistant Professor Department of Electronics and Instrumentation Engineering, NIT, Tiruchirapalli
9	Vishal D	IV BME	Application, Manufacturing Methods & Product Design in Biomedical Engineering	Dr. S. Vinodh Professor Department of Production Engineering,NIT,Tiruchirapalli
10	Deepa Shree A	IV BME	Role of Industry 4.0 Technologies with reference to Biomedical Application	Dr. S. Vinodh Professor Department of Production Engineering,NIT,Tiruchirapalli
11	Neelambari S	III BME	Optimizing Production processes for Biomedical Equipment Manufacturing: “A study on efficiency enhancement and quality control	Dr. M. Vasu Assistant Professor Department of Production Engineering, NIT, Tiruchirapalli
12	PreethiJeniya A	III BME	Optimizing Production processes for Biomedical Equipment Manufacturing: “A study on efficiency enhancement and quality control	Dr. M. Vasu Assistant Professor Department of Production Engineering, NIT, Tiruchirapalli

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PAPER

Elusive exotic structures and their collisional dynamics in (2+1)-dimensional Boiti-Leon-Pempinelli equation

R Radha[1,*], **Sudhir Singh**[2], **C Senthil Kumar**[3] **and Senyue Lou**[4]

[1] Centre for Nonlinear Science (CeNSc), Post-Graduate and Research Department of Physics, Government College for Women (Autonomous), Kumbakonam-612001, India

[2] Department of Mathematics, National Institute of Technology, Tiruchirappalli 620015, India

[3] Department of Physics, Vinayaka Mission's Kirupananda Variyar Engineering College, A Constituent College of Vinayaka Mission's Research Foundation (Deemed to be University) NH-47, Sankari Main Road, Periyaseeragapadi, Salem-636308, India

[4] School of Physical Science and Technology, Ningbo University, Ningbo, 315211, People's Republic of China

[*] Author to whom any correspondence should be addressed.

E-mail: vittal.cnls@gmail.com

Keywords: localized solutions, truncated Painleve' expansion approach, singular manifold, dromions, lumps, rogue waves, breathers

Abstract

In this paper, we investigate the (2+1) dimensional Boiti-Leon-Pempinelli (BLP) equation employing truncated Painlevé expansion approach and extract a plethora of localized nonlinear waves, including multi-dromions, multi-lumps, multi-rogue waves, generalized-breathers etc. The dromions are characterized as bright, dark and mixed (bright-dark) based on their intensity. The collisional dynamics of dromions shows that they change their shape or form upon interaction in addition to undergoing a phase change. The lump solutions of orders one and two are also extracted through appropriate test functions and observed to be non-interacting in nature. Also, the first-order and second-order rogue waves are also obtained through rational polynomials and shown to be unstable. The generalized breathers are obtained by utilizing the three-wave test function. The highlights of our investigation is that one encounters a strange coherent structure called 'dromion filter' which contains a dynamic and a stationary dromion. In addition, we are also able to unearth a 'coexistent dromion-line soliton'.

1. Introduction

The advent of dromions[1–5] had a huge impact (bearing) in the quest for subsequent identification of other localized solutions like rogue waves [6–9], interaction waves [10–13] and lumps [14–19]. While dromions which originate at the cross point of the intersection of two nonparallel ghost solitons decay exponentially in all directions and are being driven by boundaries, Lumps are essentially algebraically decaying solutions which do not interact with each other. The above class of localized solutions find applications in a variety of contexts. While rogue waves have been identified in hydrodynamics [20], Bose–Einstein Condensates [21], Plasma Physics [22], etc., dromions appear in the domain of meta materials as plasmonn dromions[23], in the study of flexural-gravity waves [24], electron acoustic waves in space plasmas [25], in ultrafast lasers [26], etc.

The richness in the structure of localized solution in the (2+1) dimensional nonlinear partial differential equations(pdes) can be attributed to the existence of lower dimensional arbitrary functions of space and time and it is believed that manouevring these lower dimensional arbitrary functions of space and time can give rise to newer and unknown localized structures. It is this peculiar perspective of the (2+1) dimension nonlinear pdes which makes their investigation interesting even today. In this direction, we wish to analyse the localized solutions admitted by Boiti-Leon-Pempinelli (BLP) equation [27].

$$v_t - v_{xx} - 2uv_x = 0, \tag{1}$$

$$u_{yt} - (u^2 - u_x)_{xy} - 2v_{xxx} = 0. \tag{2}$$

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This equation describes the dynamics of the horizontal velocity component propagating in an infinite narrow channel having constant depth. This equation belongs to a family of long dispersive wave equations. One variant of the long dispersive equation has already been investigated by Radha and Lakshmanan [28] using Hirota method and localized solutions for the composite field have been generated. Recently, Radha *et al* employing Painlevé truncated approach [29], constructed localized solutions like dromions, lumps and rogue waves of the long dispersive wave equation [29],

The reduction of the BLP equation to one dimension gives one dimensional dispersive long wave equation and the Burgers equation for different choices of transformations. Yue *et al* have obtained the travelling wave solutions using ansatz approach [30], while Mu *et al* have studied BLP equation using singular manifold method and obtained rogue waves and other localized structures like kinks and compactons[31]. It should be emphasized that exponentially localized solutions like dromions and their collision dynamics have never been reported so far.

In this paper, by employing truncated Painlevé approach [32–34], we have constructed a more general solution in terms of arbitrary functions. We have also generated localized solutions like dromions and studied their interaction. Other localized solutions like multi-rogue waves, multi-lumps and breathers have also been constructed. The highlight of our investigation is that we end up generating novel localized solutions called "dromion filters" and "coexistent dromion-line soliton", which have never been reported so far, thereby adding to the list of localized solutions of (2+1) dimensional nonlinear pdes.

The plan of the paper is as follows, In section 2, we solve the BLP equation using truncated Painlevé approach and obtain its solution in terms of lower dimensional arbitrary functions of space and time. In section 3, we obtain a plethora of localized solutions and analyze their interactions. In section 4, we transform the BLP equation into a linear equation through a logarithmic transformation and study the dynamics of the solution. A brief summary of the results obtained has been reported in conclusion.

2. Localized nonlinear waves through truncated Painlevé expansion approach

We now consider the (2+1) dimensional Boiti-Leon-Pempinelli (BLP) equations (1) and (2) and effect a local Laurent expansion in the neighbourhood of a non characteristic singular manifold $\phi(x; y; t) = 0, \phi_x \neq 0, \phi_y \neq 0$. Assuming the leading orders of the solutions of equations (1) and (2) to have the form

$$u = u_0\phi^{\alpha}, \quad v = v_0\phi^{\beta}. \tag{3}$$

where u_0 and v_0 are the analytic functions of (x, y, t) and α and β are integers to be determined, we now substitute equation (3) into equations (1) and (2) and balance the most dominant terms to obtain

$$\alpha = \beta = -1. \tag{4}$$

along with the constraints

$$u_0 = \phi_x, \ v_0 = \phi_y. \tag{5}$$

By truncating the Laurent series of the solutions of equations (1) and (2) at the constant level term, one obtains the following Bäcklund transformation,

$$u = \frac{u_0}{\phi} + u_1, \tag{6}$$

$$v = \frac{v_0}{\phi} + v_1. \tag{7}$$

Assuming the following seed solution,

$$u_1 = u_1(x, t), \quad v_1 = 0. \tag{8}$$

we now substitute equations (6) and (7) with the above seed solution equation (8) into equations (1) and (2) and collect the coefficients of (ϕ^{-3}, ϕ^{-4}) to obtain

$$-2v_0\phi_x^2 + 2u_0v_0\phi_x = 0, \tag{9}$$

$$-6u_0\phi_y\phi_x^2 + 12v_0\phi_x^3 - 6u_0^2\phi_y\phi_x = 0. \tag{10}$$

From equations (9) and (10), we get

$$u_0 = \phi_x \tag{11}$$

and

$$v_0 = \phi_y. \tag{12}$$

Collecting the coefficients of (ϕ^{-2}, ϕ^{-3}) we have,

$$-v_0\phi_t - 2u_0v_{0x} + v_0\phi_{xx} + 2v_{0x}\phi_x + 2u_1v_0\phi_x = 0, \tag{13}$$

$$\begin{aligned}&2u_0\phi_t\phi_y + 4u_0u_{0x}\phi_y + 4u_0u_{0y}\phi_x + 2u_0^2\phi_{xy} - 4u_0u_1\phi_y\phi_x + 4u_{0x}\phi_x\phi_y\\ &+2u_{0y}\phi_x^2 + 4u_0\phi_x\phi_{xy} - 12v_{0x}\phi_x^2 - 12v_0\phi_x\phi_{xx} + 2u_0\phi_y\phi_{xx} = 0.\end{aligned} \tag{14}$$

Substituting equations (11, 12) into equations (13) and (14), we get

$$u_1 = \frac{(\phi_t - \phi_{xx})}{2\phi_x}. \tag{15}$$

Proceeding further and collecting the coefficients of (ϕ^{-1}, ϕ^{-2}), we have,

$$v_{0t} - v_{0xx} - 2v_{0x}u_1 = 0, \tag{16}$$

$$\begin{aligned}&-u_{0y}\phi_t - u_{0t}\phi_y - u_0\phi_{yt} - 2u_{0y}u_{0x} - 2u_0u_{0xy} + 2u_{0x}u_1\phi_y + 2u_0u_{1x}\phi_y\\ &+ 2u_{0y}u_1\phi_x + 2u_0u_{1y}\phi_x + 2u_0u_1\phi_{xy} - u_{0xxx}\phi_y - 2u_{0xy}\phi_x - 2u_{0x}\phi_{xy}\\ &- u_{0y}\phi_{xx} - u_0\phi_{xxy} + 6v_{0xx}\phi_x + 6v_{0x}\phi_{xx} + 2v_0\phi_{xxx} = 0.\end{aligned} \tag{17}$$

Substituting equations (11), (12) and (15) in equation (16), we obtain a bilinear equation as

$$\phi_x\phi_{yt} - \phi_{xxy}\phi_x - \phi_{xy}\phi_t + \phi_{xy}\phi_{xx} = 0. \tag{18}$$

It is obvious that equation (17) becomes an identity. The structure of the bilinear equation (18) suggests that the manifold can be partitioned as

$$\phi = \phi_1(x, t) + \phi_2(y) + \phi_3(x)\phi_4(t). \tag{19}$$

where $\phi_1(x, t)$, $\phi_2(y)$, $\phi_3(x)$, $\phi_4(t)$ are arbitrary functions of the indicated variables.

In addition to the above, the BLP equation can be related to the heat equation. For example, for the manifold $\phi = U(x_1, y, t_1)$, where $x_1 = f_1(y)[\sqrt{f_{2t}(t)}\,x + x_0(t)]$, $t_1 = t_0(y) + f_1(y)^2 f_2(t)$, where, $f_1(y), f_2(t), x_0(t), t_0(y)$ are arbitrary functions of the indicated variables. $U(x_1, y, t_1)$ is any solution of the heat equation $U_{t_1} = U_{x_1x_1}$. Heat equation possesses infinitely many solutions with infinitely many arbitrary many functions. For instance,

$$\begin{aligned}U = &\sum_1^N a_i(y)exp(k_i(y)x_1 + k_i(y)^2t_1) + \sum_1^M (b_i(y)cos(p_i(y)x_1 + 2p_i(y)q_i(y)t_1 + r_i(y))\\ &\times exp(q_i(y)x_1 + (q_i(y)^2 - p_i(y)^2)t_1)),\end{aligned} \tag{20}$$

where a_i, b_i, k_i, p_i, q_i, r_i are arbitrary functions of y.

Substituting equation (19) in equations (11), (12), (15) leads to

$$u_0 = \phi_{1x} + \phi_{3x}\phi_4, \tag{21}$$

$$v_0 = \phi_{2y}, \tag{22}$$

$$u_1 = \frac{\phi_{1t} + \phi_3\phi_{4t} - \phi_{1xx} - \phi_{3xx}\phi_4}{2\phi_{1x} + 2\phi_{3x}\phi_4}, \tag{23}$$

$$v_1 = 0. \tag{24}$$

Again, collecting the coefficients of (ϕ^0, ϕ^{-1}) we have,

$$u_{0yt} - 2v_{0xxx} - 2u_{0xy}u_1 - 2u_{0x}u_{1y} - 2u_{0y}u_{1x} - 2u_0u_{1xy} + u_{0xxy} = 0. \tag{25}$$

Substituting equations (11), (12) in equation (25), we obtain the trilinear form,

$$\begin{aligned}&\phi_x^2\phi_{xyt} - \phi_x^2\phi_{xxxy} - \phi_x\phi_{xxy}\phi_t + \phi_x\phi_{xxy}\phi_{xx}\\ &-\phi_x\phi_{xy}\phi_{tx} + \phi_x\phi_{xy}\phi_{xxx} + \phi_{xy}\phi_{xx}\phi_t - \phi_{xy}\phi_{xx}^2 = 0,\end{aligned} \tag{26}$$

which is an identity. Thus, the (2+1) dimensional Boiti-Leon-Pempinelli (BLP) equations (1) and (2) has been solved completely for the initial assumption of seed solutions (8) through truncated Painlevé approach and the closed form of the fields u and v are given by

$$u = \frac{\phi_{1x} + \phi_{3x}\phi_4}{\phi_1(x, t) + \phi_2(y) + \phi_3(x)\phi_4(t)} + \frac{\phi_{1t} + \phi_3\phi_{4t} - \phi_{1xx} - \phi_{3xx}\phi_4}{2\phi_{1x} + 2\phi_{3x}\phi_4}, \tag{27}$$

$$v = \frac{\phi_{2y}}{\phi_1(x, t) + \phi_2(y) + \phi_3(x)\phi_4(t)}. \tag{28}$$

The corresponding potential field is written as:

$$w = -u_y = -v_x = \frac{\phi_{2y}(\phi_{1x} + \phi_{3x}\phi_4)}{(\phi_1(x,\, t) + \phi_2(y) + \phi_3(x)\phi_4(t))^2}. \tag{29}$$

It may be noted that the above solution is a more general solution with four arbitrary functions $\phi_1(x, t)$, $\phi_2(y)$, $\phi_3(x)$ and $\phi_4(t)$. A special case of the above solution, $\phi_3(x) = 0$ and $\phi_4(t) = 0$ was identified by Mu *et al* [31].

3. Localized nonlinear structures in (2+1) dimensional BLP equation

In this section, we have extracted several physically interesting localized coherent structures like dromions, lumps, rogue waves, breathers and line solitons and discussed their dynamics.

3.1. Dromions

Here, we have extracted the dromions using suitable test functions. Dromions are exponentially localized structures decaying in all directions. We have obtained two sets of dromions, namely (2, 1) and (2, 2) dromions. Further, we have also studied the asymptotic analysis of (2, 1) dromions besides identifying a unique structure called 'dromion filters'.

3.1.1. (2,1) Dromion solution

To construct a (2,1) dromion solution, we choose the following test function

$$\phi_1(x,\, t) = a_1 \tanh(b_1 x - b_2 t + e_1) + a_2 \tanh(b_3 x - b_4 t + e_2) + g_1, \tag{30}$$

$$\phi_2(y) = c_1 \tanh(d_1 y + e_3) + g_2, \tag{31}$$

$$\phi_3(x) = a_3 \tanh(x), \tag{32}$$

$$\phi_4(t) = 0, \tag{33}$$

where $a_i, b_j, e_i, g_l; i = 1, 2, 3; j = 1, 2, 3, 4; l = 1, 2$ and c_1, d_1 are arbitrary real constants. Using equation (29), the (2,1) dromion takes the following form

$$w = \frac{c_1 d_1 (a_1 b_1 \mathrm{sech}^2(\psi_1) + a_2 b_3 \mathrm{sech}^2(\psi_2))\mathrm{sech}^2(\psi_3)}{(g_1 + g_2 + a_1 \tanh(\psi_1) + a_2 \tanh(\psi_2) + c_1 \tanh(\psi_3))^2}, \tag{34}$$

where $\psi_1 = e_1 - b_2 t + b_1 x$, $\psi_2 = e_2 - b_4 t + b_3 x$ and $\psi_3 = e_3 + d_1 y$. The time evolution of bright-bright, dark-dark and dark-bright(mixed) dromions is shown in figures 1–3 respectively.

Now, to understand the nature of interaction of dromions, we perform the asymptotic analysis of (2,1) dromion solution.

3.1.2. Asymptotic analysis of (2,1) dromion solution

Since both the dromions in figures 1(a) and (c) corresponding to the solution (34) are traveling along the x-direction in opposite directions, it is enough to do this analysis for $y = 0$ (and $e_3 = 0$ so that $g_2 = 0$). Similar analysis holds good for any other value of y and $e_3 \neq 0$. This restriction corresponds to the cross section of dromions, which are essentially solitons. We analyze the limits $t \to -\infty$ and $t \to +\infty$ separately so as to understand the interaction of dromions centered around $u_1 \approx 0$ or $u_2 \approx 0$. Without loss of generality, let us assume $b_2 > b_4$ and $b_1 < b_3$. Then, we find in the limit $t \to \pm\infty$, u_1 and u_2 take the following limiting values. (1) As $t \to -\infty$:

$$u_1 \approx 0,\; u_2 \to -\infty, \tag{35}$$

$$u_2 \approx 0,\; u_1 \to +\infty. \tag{36}$$

(2) As $t \to +\infty$:

$$u_1 \approx 0,\; u_2 \to +\infty, \tag{37}$$

$$u_2 \approx 0,\; u_1 \to -\infty. \tag{38}$$

1 $\dot{B}$ efore interaction (as $t \to -\infty$): For $u_1 \approx 0$, $u_2 \to -\infty$ and $a_1 = 1; a_2 = 1,, c_1 = 1$, the (2,1) dromion solution (34) becomes (soliton solution corresponding to dromion 1)

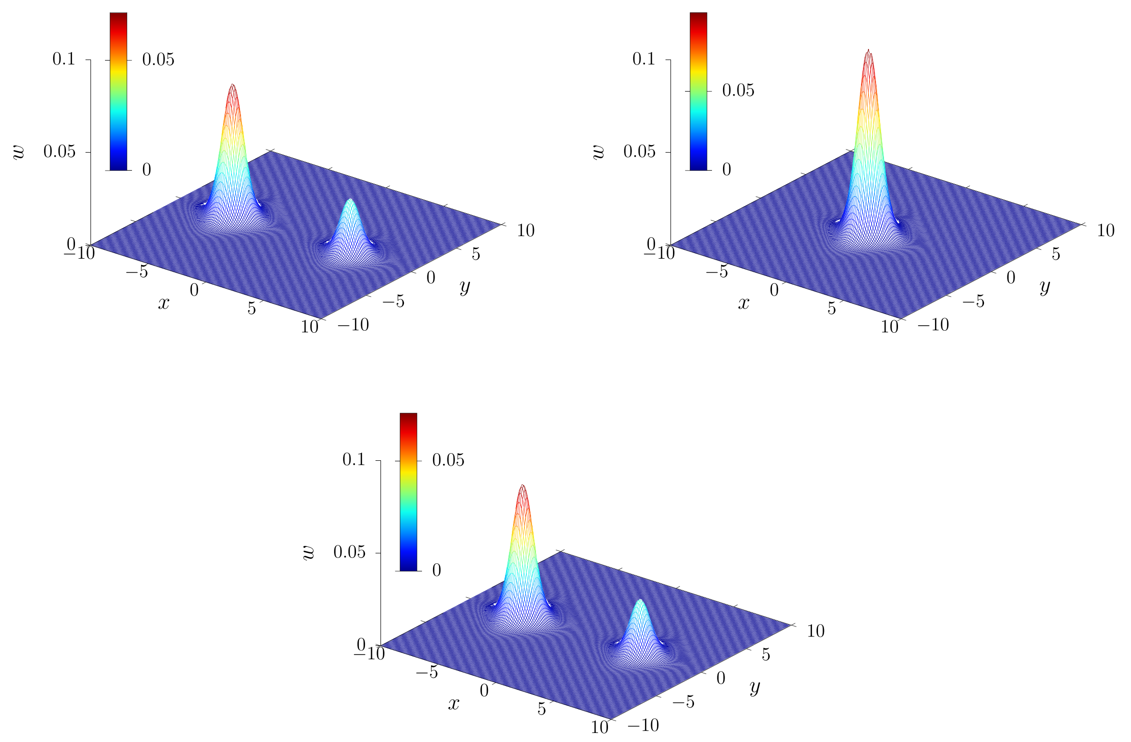

Figure 1. Time evolution (2,1) bright dromions.

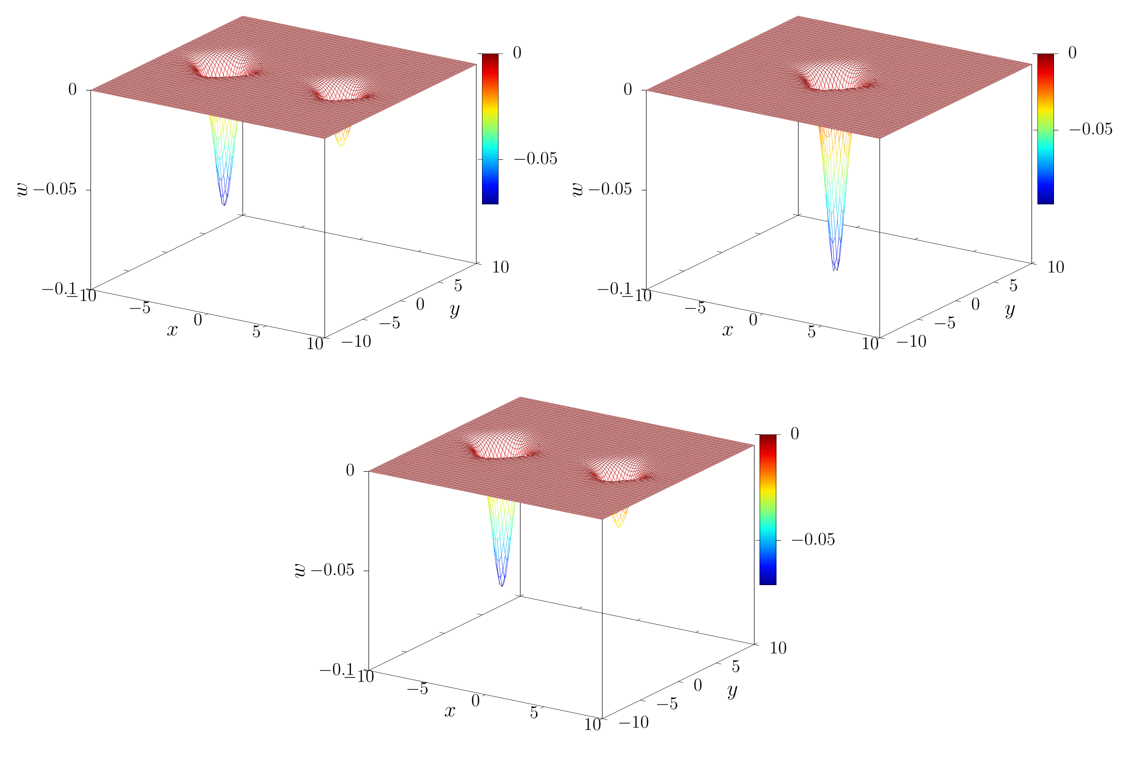

Figure 2. Time evolution (2,1) dark dromions.

$$w = \frac{b_1 d_1}{g_1(g_1 - 2)}\mathrm{sech}^2(u_1 + \delta_1),\ \delta_1 = \frac{1}{2}\log\left[\frac{g_1}{g_1 - 2}\right]. \tag{39}$$

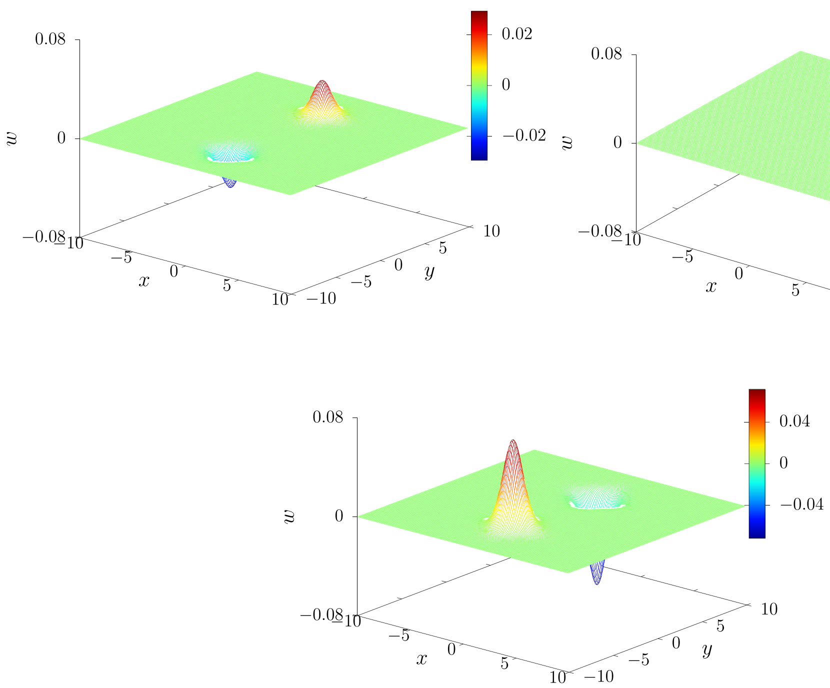

Figure 3. Time evolution (2,1) bright-dark dromions.

For $u_2 \approx 0, u_1 \to +\infty$ the solution given by equation (34) becomes (soliton solution corresponding to dromion 2)

$$w = \frac{b_3 d_1}{g_1(g_1+2)}\operatorname{sech}^2(u_2 - \delta_2),\ \delta_2 = \frac{1}{2}\log\left[\frac{g_1}{g_1+2}\right]. \tag{40}$$

2 Ȧ fter interaction (as $t \to +\infty$): For $u_1 \approx 0,\ u_2 \to +\infty$ the solutions (34) becomes (soliton solution corresponding to dromion 1)

$$w = \frac{b_1 d_1}{g_1(g_1+2)}\operatorname{sech}^2(u_1 - \delta_2), \tag{41}$$

For $u_2 \approx 0, u_1 \to -\infty$, the solutions (34) becomes (soliton solution corresponding to dromion 2)

$$w = \frac{b_3 d_1}{g_1(g_1-2)}\operatorname{sech}^2(u_2 + \delta_1). \tag{42}$$

From the above analysis, we observe that after interaction, there is a decrease in amplitude of the first dromion and increase in amplitude of the second dromion . Another interesting feature is that the dromions undergo a phase change during interaction.

The (2,1) bright dromion is plotted in figure 1 for the common parametric choice $a_2 = a_3 = b_1 = b_3 = b_4 = c_1 = 1, e_1 = e_2 = e_3 = 0, g_1 = 2, g_2 = 3$ and $a_1 = d_1 = 1, b_2 = -1$. From the figure 1, it is obvious that the dromions are traveling along the x-direction with the same velocity in opposite directions in the $x - y$ plane. In addition, the change of shape (or form) and phase of dromions are also evident from figure 1.

And, evolution of dark dromions are studied for the same parametric choices except for $a_1 = 1$, $d_1 = b_2 = -1$ (shown in in figure 2) while mixed (bright-dark) dromions are plotted again for the same parametric choices except $a_1 = d_1 = b_2 = -1$ (shown in figure 3).

It should be emphasized that the concept of bright (figure 1), dark (figure 2) and bright-dark(mixed) dromions (figure 3) has been brought out to the fore for the first time and the three parameters, namely a_1, b_2 and d_1 play a crucial in the transition of bright to dark or bright to mixed dromions.

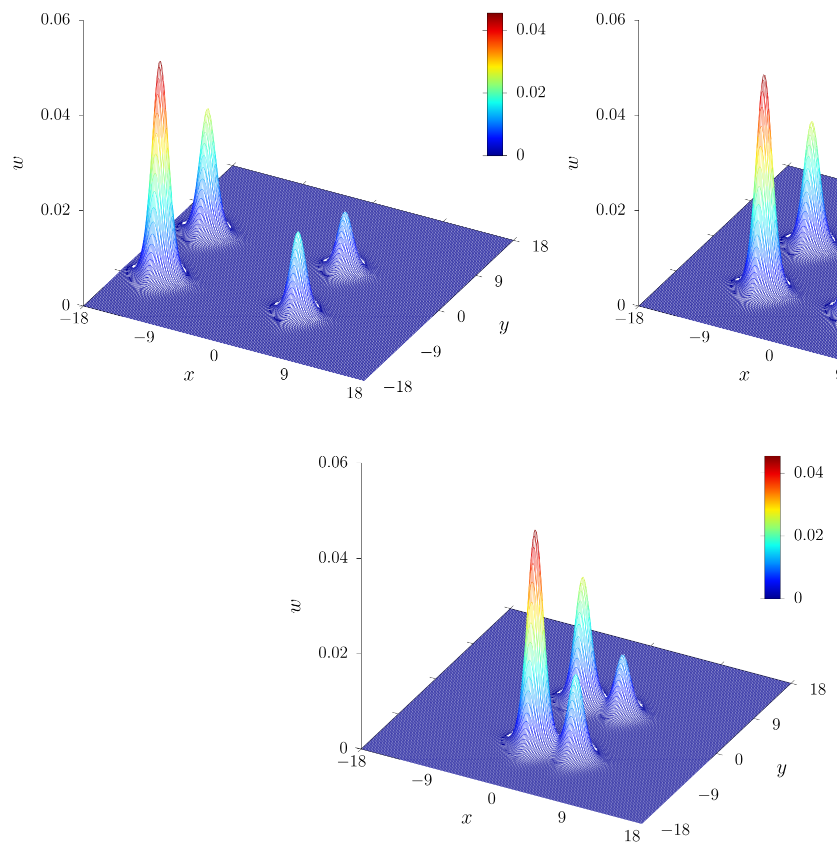

Figure 4. Time evolution (2,2) dromions.

Further, the higher-order dromions can also be constructed and studied. We have constructed the (2,2) dromions and discussed their evolutionary mechanics.

3.1.3. (2,2) Dromion solution

To construct (2,2) dromion solution using equation (29), we choose the following test functions

$$\phi_1(x,\ t) = a_1 \tanh(b_1 x - b_2 t + e_1) + a_2 \tanh(b_3 x - b_4 t + e_2) + g_1, \tag{43}$$

$$\phi_2(y) = c_1 \tanh(d_1 y + e_3) + c_2 \tanh(d_2 y + e_4) + g_2, \tag{44}$$

$$\phi_3(x) = c_3 \tanh(x) + c_4 \tanh(x), \tag{45}$$

$$\phi_4(t) = 1, \tag{46}$$

where $a_i, b_j, c_k, d_i, e_j, g_i$; $i = 1, 2$; $j = 1, 2, 3, 4$ and $k = 1, 2, 3$ are arbitrary real constants.

Using (3.1.3) and (29), the higher order dromion solutions are extracted. Their time evolution is shown in figure 4, for the parameters $a_1 = b_1 = c_1 = d_1 = a_2 = b_2 = c_2 = d_2 = b_3 = c_3 = b_4 = c_4 = e_4 = 1, g_1 = g_2 = 5$ and $e_1 = e_2 = 9, e_3 = 10$.

Further, we can construct other higher-order dromion (more than six peaks) solutions using appropriate test functions.

3.2. Dromion filters

We observe that the time evolution of (2,2) dromion exhibits an interesting charater. For a specific parametric choice $a_1 = 4$; $b_1 = b_2 = a_2 = b_3 = b_4 = c_1 = d_1 = c_2 = d_2 = c_3 = c_4 = 1$ and $e_1 = e_2 = e_3 = e_4 = g_1 = g_2 = 5$, we observe that there are only two dromions with one being dynamic and the other static. As time evolves, there is an interaction between the two. During interaction, the stationary dromion behaves like a filter. After interaction, the amplitude of the stationary dromion grows, while the amplitude of the dynamic dromion is reduced as shown in figure 5. In this way, the stationary dromion behaves like a filter and reduces the amplitude of the dynamic dromions.

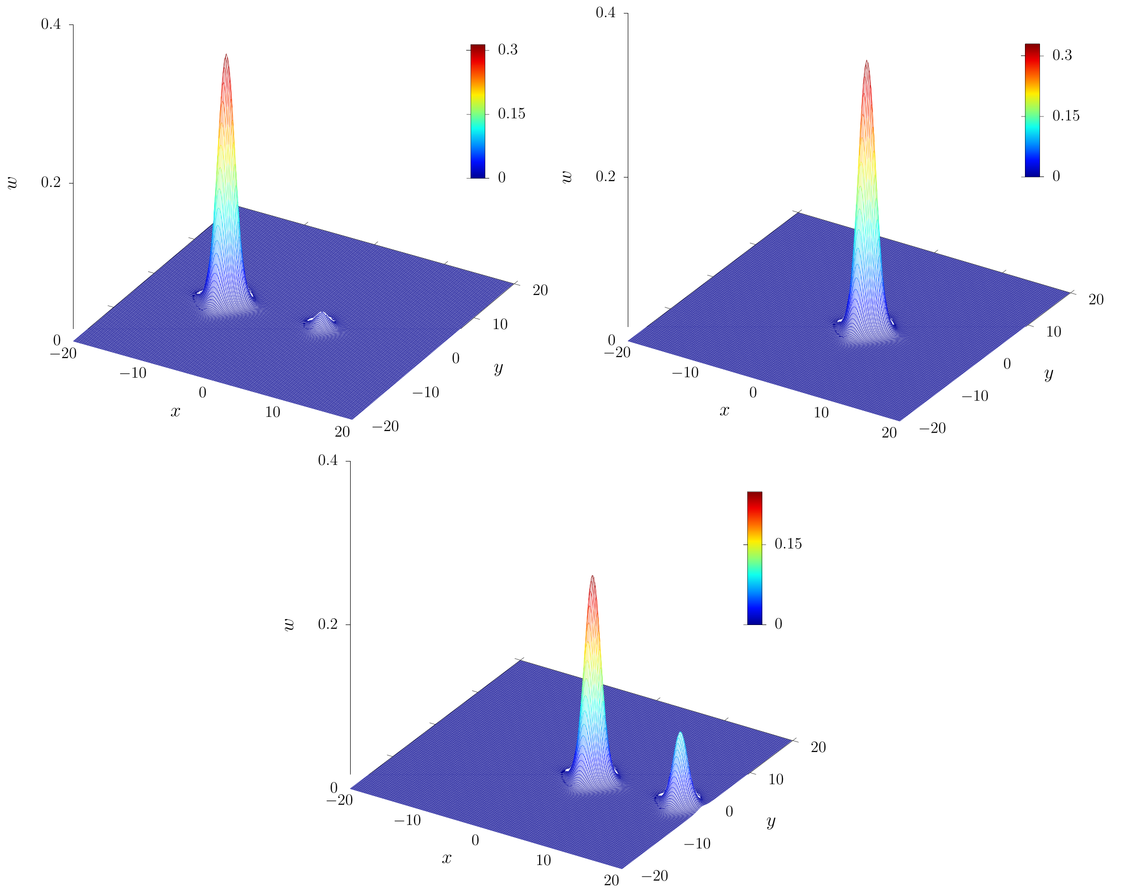

Figure 5. Time evolution of dromion filter.

3.3. Lumps

Lumps are localized nonlinear structures decaying algebraically in all directions in space. Generally, lumps occur in (2+1) dimensional nonlinear pdes. Recently, Wen-Xiu Ma studied the lump solutions of the (2+1)-dimensional Kadomtsev-Petviashvili equation through the Hirota bilinear form and by choosing a quadratic polynomial test function of the form $\phi(x, y, t) = A^2 + B^2 + c_0$, where $A = (\alpha_1 x + \beta_1 y + \gamma_1)^2$, $B = (\alpha_2 x + \beta_2 y + \gamma_2)^2$ and $\alpha_i, \beta_i, \gamma_i, i = 1, 2$ and c_0 are reals to be determined [35]. Interestingly, this prototype structure gained much attention since it appears in many physical systems. For the BLP equation, the single lump has already been obtained in [36]. But, multi-lump solutions have not yet been generated so far as there was no algorithm to construct them.

To construct one lump solution using equation (29), we choose

$$\phi_1(x,\ t) = \frac{1}{(1 + (j_1 x - j_2 t - j_3))^2}, \tag{47}$$

$$\phi_2(y) = \frac{1}{1 + (ky - h)^2}, \tag{48}$$

$$\phi_3(x) = 1, \tag{49}$$

$$\phi_4(t) = 0, \tag{50}$$

where j_i; $i = 1, 2, 3$ and h, k are arbitrary real constants. Accordingly, one lump solution takes the following form

$$w = \frac{4 j_1 k(h - ky)(j_3 + j_2 t - j_1 x - 1)}{((h - ky)^2 + 2 j_3 (j_2 t - j_1 x - 1) + (j_2 t - j_1 x)^2 + 2 j_1 x - 2 j_2 t + j_3{}^2 + 2)^2}. \tag{51}$$

The time evolution of single-lump solution is shown in figure 6, for the parametric choice $j_1 = 1.5, j_2 = 0.5$, $j_3 = 0.4, k = 2.5$ and h=0.1.

The obtained lump in figure 6 is having paired peak in $x - y$-plane. The above procedure can be extended to obtain higher order lumps as coupled paired peaks.

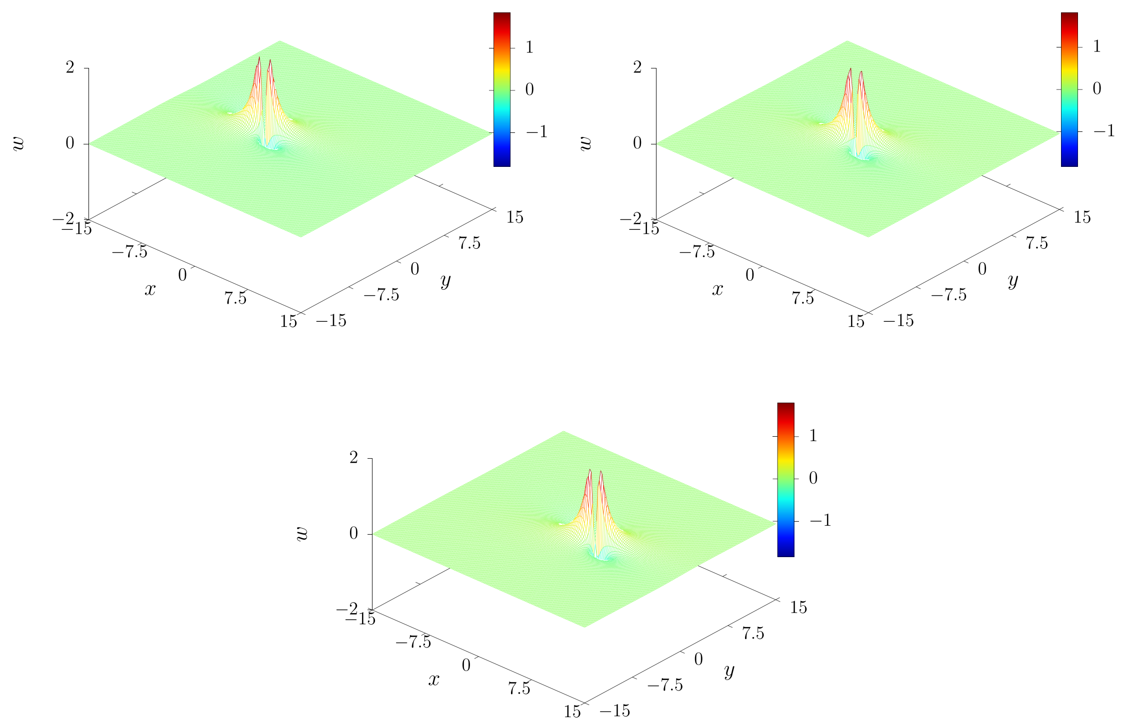

Figure 6. Evolution of single-lump solution.

For example,to construct a two lump solution using equation (29), we choose

$$\phi_1(x,\,t) = \frac{1}{(1+(j_1x - j_2t - j_3))^2} + \frac{1}{(1+(j_4x - j_5t - j_6))^2}, \tag{52}$$

$$\phi_2(y) = \frac{1}{1+(ky-h)^2} + \frac{1}{1+(k_1y-h_1)^2}, \tag{53}$$

$$\phi_3(x) = 2, \tag{54}$$

$$\phi_4(t) = 0, \tag{55}$$

where j_i; $i = 1, 2, 3, 4, 5, 6$ and h, k, h_1, k_1 are arbitrary real constants.

Using equation (29), the 2-lumps are obtained and its time evolution is shown in figure 7 for the parametric choices $j_1 = j_2 = j_3 = j_4 = j_5 = h = k = k_1 = 1, j_6 = 10$, and $h_1 = 5$. The two lumps do not interact during time evolution in $x - y$-plane.

The above procedure can be easily extended to generate multi lump solution.

3.4. Rogue waves

Rogue waves are very monstrous nonlinear wave structures. A famous statement about rogue waves is that 'they appear from nowhere and disappear without a trace' [37]. Rogue waves are the most unstable nonlinear wave structures and they are also known as freak waves or monstrous waves and their occurrence is observed in several physical systems.

Here, we have constructed the rogue waves of order one and two and and analyzed their dynamics.

To construct a single rogue wave solution using equation (29), we choose

$$\phi_1(x,\,t) = \frac{cx}{(1+\alpha x^2 + dt^2)^2} + \frac{1}{(2d)^2}, \tag{56}$$

$$\phi_2(y) = \frac{3hy^4}{(1+(y-b)^2g + kny)^2}, \tag{57}$$

$$\phi_3(x) = 0, \tag{58}$$

$$\phi_4(t) = 0, \tag{59}$$

where α, b, c, d, g, h, k and n are arbitrary real constants.

The dynamical evolution of single rogue waves is shown in figure 8 We have obtained bright rogue wave wave profile for the parameters $c = 30, \alpha = 0.8, d = 0.07, h = 47, b = 0.9, g = 0.6, k = 0$ and $n = 4$. The time evolution shows the unstable nature of rogue waves.

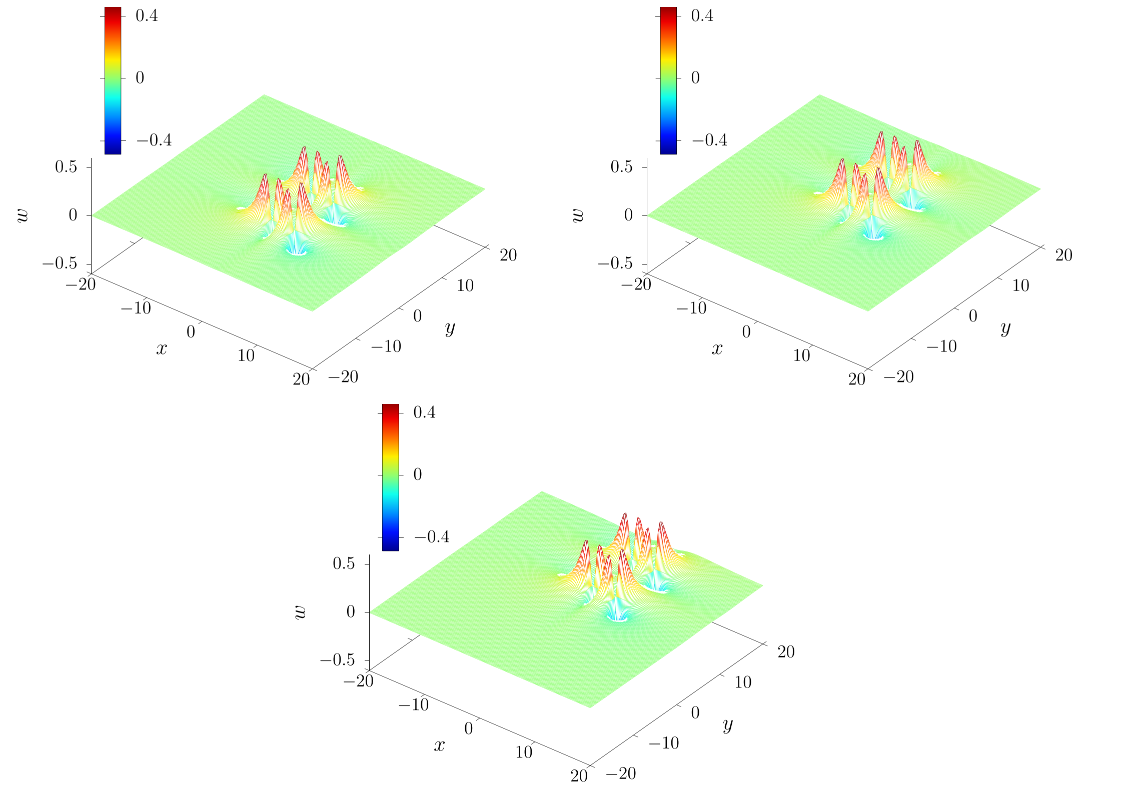

Figure 7. Evolution of two lumps.

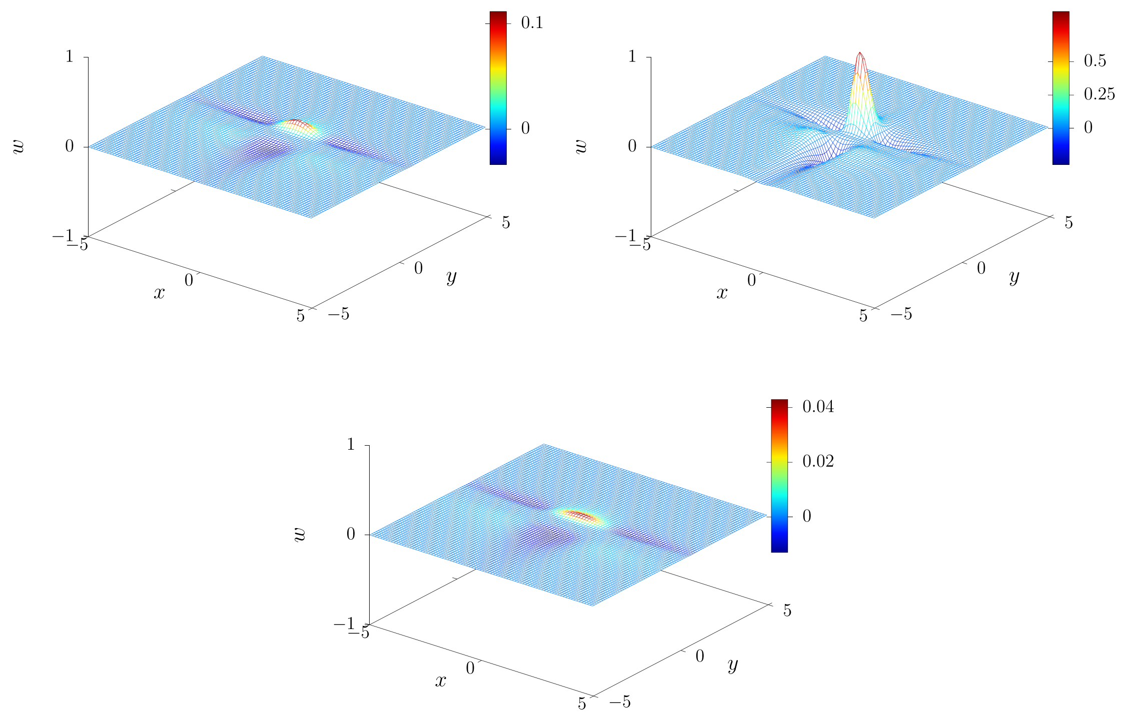

Figure 8. Evolution of one rogue wave.

Again, to construct a two rogue wave solution using equation (29), we choose

$$\phi_1(x,\, t) = \frac{cx}{(1 + \alpha x^2 + dt^2)^2} + \frac{c_1 x}{(1 + \alpha_1(x - 1)^2 + d_1(t - 1)^2)^2} + \frac{1}{(2d)^2}, \tag{60}$$

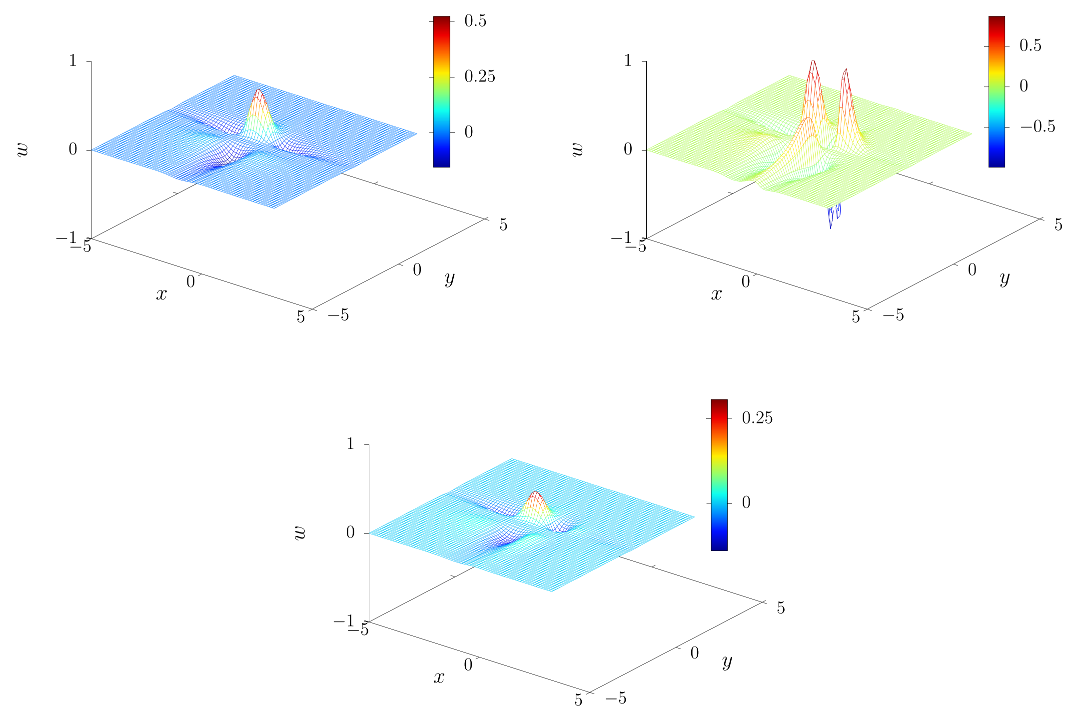

Figure 9. Evolution of two rogue waves and its contour-plot.

$$\phi_2(y) = \frac{3hy^4}{(1+(y-b)^2g+kny)^2} + \frac{3h_1y^4}{(1+(y-b_1)^2g_1+k_1n_1y)^2}, \tag{61}$$

$$\phi_3(x) = 0, \tag{62}$$

$$\phi_4(t) = 0, \tag{63}$$

where $c, c_1, h, h_1, b, b_1, g, g_1, k, k_1, n, n_1, d, d_1$ and α, α_1 are arbitrary real constants. Using equation (29), the two rogue waves are extracted and its time-evolution is shown in figure 9 for the parametric choice $c = 30, c_1 = -81$, $h = 47, h_1 = 5, b = 0.9, b_1 = -10, g = 0.6, g_1 = 5, k = 0, k_1 = 2, n = 4, n_1 = 2, d = 0.07, d_1 = 1$ and $\alpha = 0.8$, $\alpha_1 = 5$. Again, the time evolution shows its unstable nature.

3.5. Gereralized breathers

Breathers are again spatially localized structures whose amplitude oscillate in time. A homoclinic breather test function consisting of two waves has the following form:

$$\phi(x,\ t) = \alpha_1 e^{(\beta_1 x+\gamma_1 t)} + \alpha_2\, sin(\beta_2 x + \gamma_2 t) + \alpha_3 e^{(-(\beta_1 x+\gamma_1 t))}. \tag{64}$$

The above test function combines two waves, one periodic wave and another hyperbolic wave and the limiting case of the homoclinic breather waves are nothing but the rogue waves. Recently, to get the generalized breathers, a general test function called the three-wave test function [38], consisting of two hyperbolic waves and one periodic waves is being employed.

Motivated by [38], we choose the following form to obtain the localized breathers

$$\phi_1(x,\ t) = \alpha_1 e^{(\beta_1 x+\gamma_1 t)} + \alpha_2\, sin(\beta_2 x + \gamma_2 t) + \alpha_3 e^{(-(\beta_1 x+\gamma_1 t))} + \alpha_4\, cosh(\beta_3 x + \gamma_3 t), \tag{65}$$

$$\phi_2(y) = \alpha_5 e^{\beta_4 y} + \alpha_6 e^{-\beta_4 y}, \tag{66}$$

$$\phi_3(x) = \alpha_7 e^{\beta_5 x} + \alpha_8 e^{-\beta_5 x}, \tag{67}$$

$$\phi_4(t) = \alpha_9 e^{\beta_6 t} + \alpha_{10} e^{-\beta_6 t}, \tag{68}$$

where $\alpha_i, \beta_j, \gamma_k; i = 1, 2...10; j = 1, 2...6$ and $k = 1, 2, 3$ are arbitrary real constants. Using equation (29), the generalized breathers is obtained and plotted in figure 10, for the parametric choice $\alpha_1 = \beta_1 = \gamma_1 = \beta_3 = \gamma_3 = \beta_5 = \beta_6 = \alpha_{10} = 0.1, \alpha_2 = -2, \alpha_3 = \beta_4 = 2, \beta_2 = 5.1, \gamma_2 = 3, \alpha_4 = 0.03, \alpha_5 = 0.04, \alpha_6 = 0.02$ and $\alpha_7 = \alpha_8 = \alpha_9 = 1$ for $t = 0$. It is pretty obvious from figure 10 that the amplitude of breathers oscillate with time. The above method can be generalized to construct multi breather solutions.

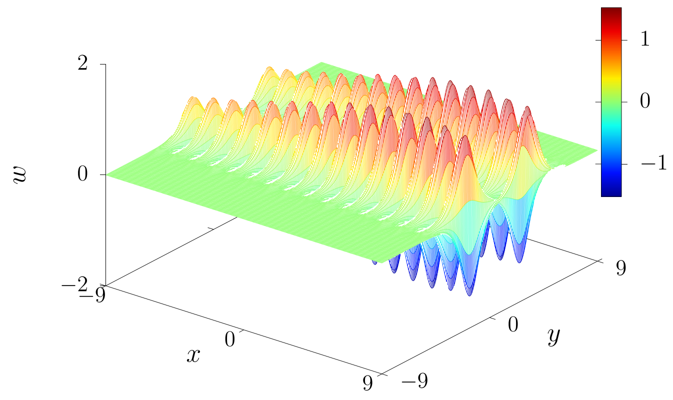

Figure 10. Snapshot of oscillating breathers.

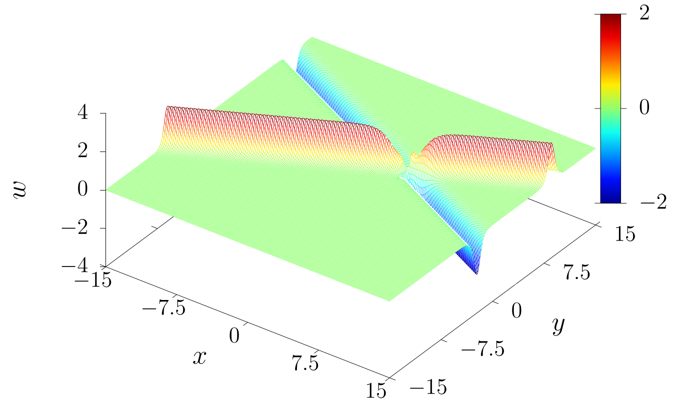

Figure 11. Snapshot of mixed line solitons.

3.6. Line solitons

To generate line solitons, we choose the following lower dimensional arbitrary functions of space and time

$$\phi_1(x,\, t) = \alpha_1\,\mathrm{sech}^2(\beta_1 x + \gamma_1 t) + \alpha_2 sech^2(\beta_2 x + \gamma_2 t), \tag{69}$$

$$\phi_2(y) = \mathrm{sech}^2(\beta_3 y + \gamma_3), \tag{70}$$

$$\phi_3(x) = \mathrm{sech}(m_1 x + n_1), \tag{71}$$

$$\phi_4(t) = \mathrm{sech}(m_2 t + n_2), \tag{72}$$

where $\alpha_i, m_i, n_i, \beta_j, \gamma_j; i = 1, 2; j = 1, 2, 3$ are arbitrary real constants. Substituting the above test functions into equation (29), we obtain mixed(dark-bright) line solitons and the profile of mixed line solitons for the parametric choice $\alpha_1 = \beta_3 = m_2 = 2, \beta_1 = \gamma_1 = \alpha_2 = \gamma_2 = \gamma_3 = n_1 = n_2 = 1$ and $\beta_2 = m_1 = 5$ for $t = 0$ is shown in figure 11. In a similar fashion, multi line solitons can also be further generated.

4. Coexistent dromion-line solitons

In this section, we explore the possibility of the coexistence of line solitons with dromions. Substituting the logarithmic transformation $u = (log\phi)_x$ and $v = (log\phi)_y$ into the BLP model (1), we obtain the following expression

$$\left(\frac{\phi_t - \phi_{xx}}{\phi}\right)_y = 0, \tag{73}$$

$$\left(\frac{\phi(\phi_{yt} - \phi_{xxy}) + (\phi_{xx}\phi_y - \phi_t\phi_y)}{\phi^2}\right)_x = 0. \tag{74}$$

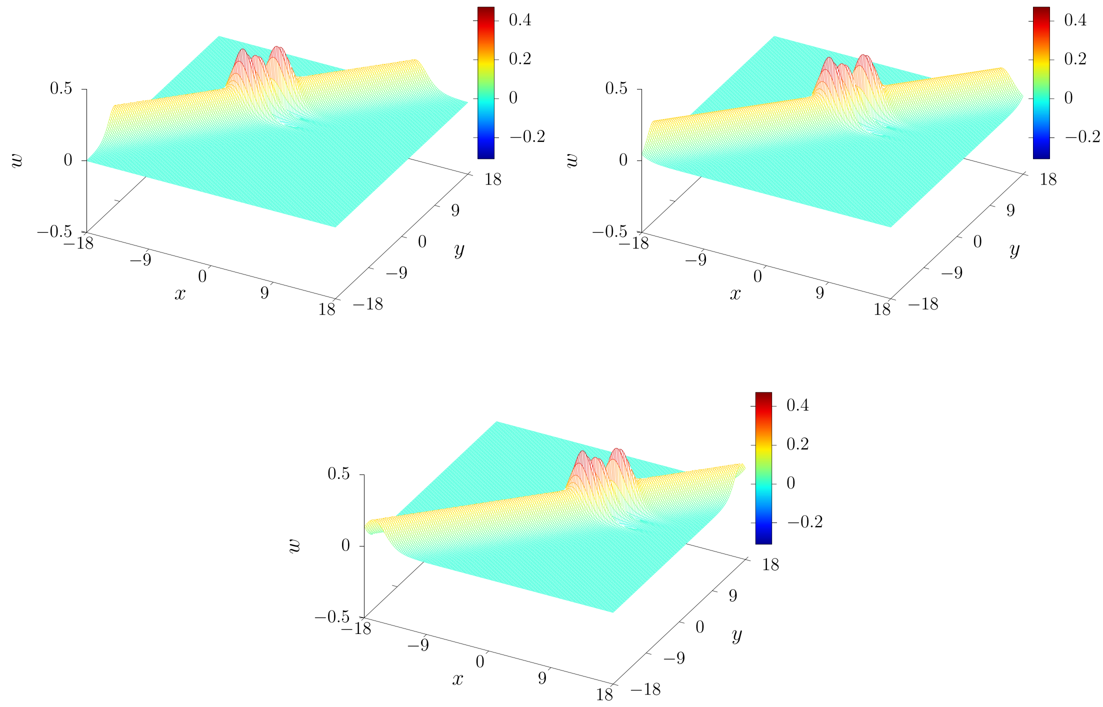

Figure 12. Evolution of coexistence dromions-line soliton for $p_1(y) = y - \text{sech}^4(y-5) - \tanh^4(2y-4) - \text{sech}^4(y-3)$.

It is obvious from the above equation that if the linear equation $(\phi_t - \phi_{xx})$ (73) vanishes, then ϕ is the solution of BLP model (1). We now choose the multi-solitary wave test function as

$$\phi = 1 + \sum_{i=1}^{n} \epsilon_i e^{\alpha_i x + \beta_i p_i(y) + \gamma_i t + \delta_i}, \tag{75}$$

where ϵ_i, α_i, β_i, γ_i and δ_i are arbitrary real constants and $p_i(y)$ are arbitrary functions.

On substituting (75) into (73) which is essentially the heat equation mentioned earlier in section 2 as another possibility of partitioning the manifold and equating to zero different powers of $e^{\alpha_i x + \beta_i p_i(y) + \gamma_i t + \delta_i}$, we obtain the following parameter restriction $\gamma_i = \alpha_i^2$. For $n = 1$, We have the potential function as

$$w = -u_y = -v_x = \frac{-\alpha_1 \beta_1 p_1{}'(y)\, \epsilon_1 e^{(\alpha_1 x + \beta_1 p_1(y) + \alpha_1^2 t + \delta_1))}}{(1 + \epsilon_1 e^{(\alpha_1 x + \beta_1 p_1(y) + \alpha_1^2 t + \delta_1)})^2}. \tag{76}$$

The time evolution of the potential w (76) is shown in figure 12 for the choice of parameters $\alpha_1 = -0.9$, $\beta_1 = 0.9$, $\delta_1 = 0.45$ and $\epsilon_1 = 0.1$. The structure shown above shows the coexistence of dromions and line solitons known as 'coexistent dromion-line solitons'. The above coherent structure is reminiscent of induced dromions of (2+1) nonlinear Schrödinger (NLS) equation [39].

5. Conclusion

In this work, we have investigated the (2+1)-dimensional Boiti-Leon-Pempinelli (BLP) equation and employed the truncated Painlevé expansion approach to construct localized solutions like multi-dromions, multi-lumps, multi-rogue waves, generalized-breathers and line solitons. The shape and phase of dromions are found to undergo change which is confirmed by the asymptotic analysis. The noninteracting nature of algebraically decaying lumps and the unstable nature of rogue waves are also brought out. The highlight of the results is that we have been able to unearth a novel coherent structure called 'dromion filters' comprising of a static and a dynamic dromion. In addition, we have also identified a new structure called 'coexistent dromion-line soliton'. Further, the construction of bright, dark and mixed dromions will certainly add to the richness in the structure of localized solutions. We do believe that the identification of new localized solutions will keep the investigation of (2+1) dimensional nonlinear pdes alive in the coming years.

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Data availability statement

No new data were created or analysed in this study.

ORCID iDs

R Radha https://orcid.org/0000-0002-5969-580X
C Senthil Kumar https://orcid.org/0000-0001-6794-0150
Senyue Lou https://orcid.org/0000-0002-9208-3450

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