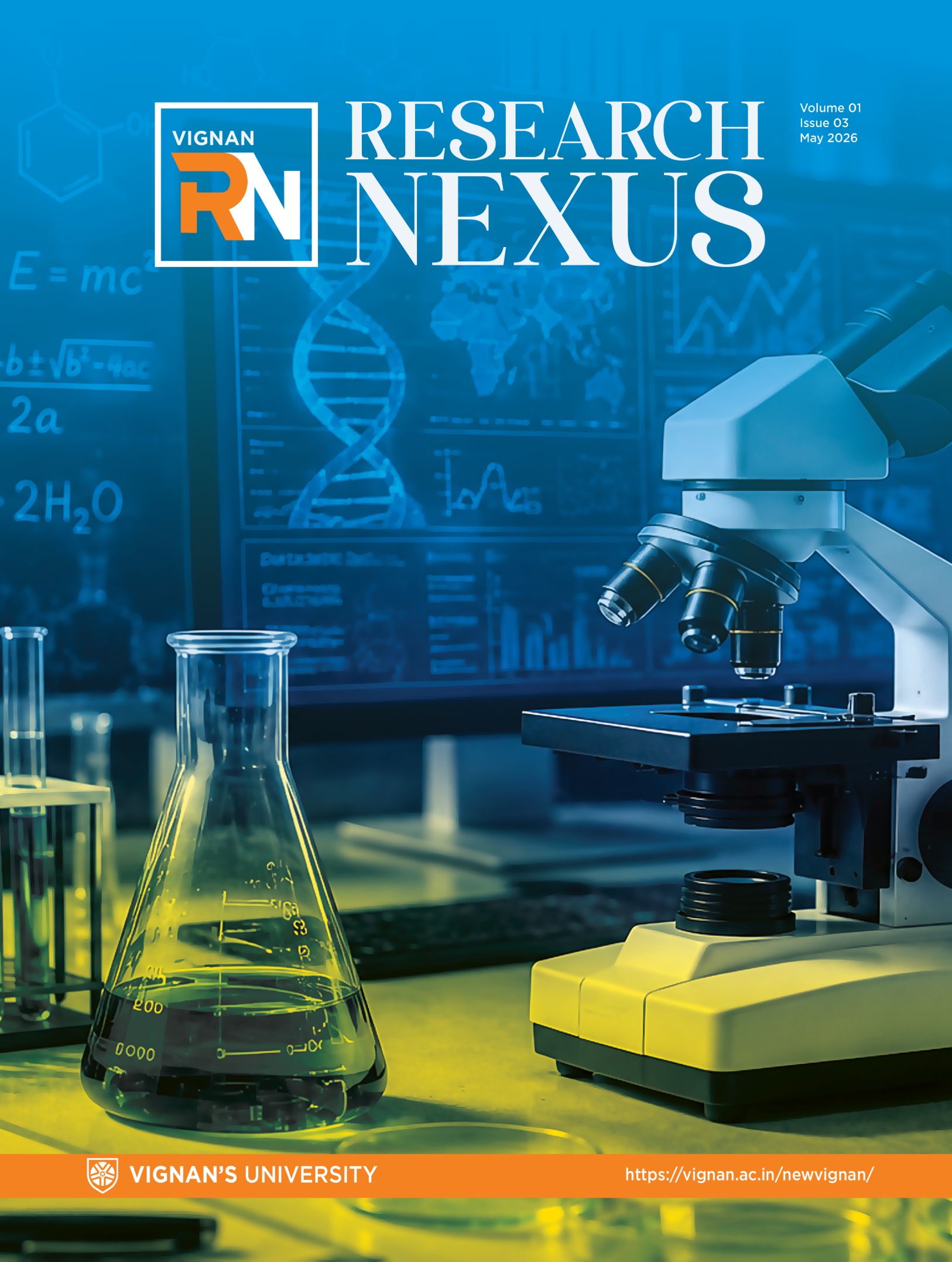
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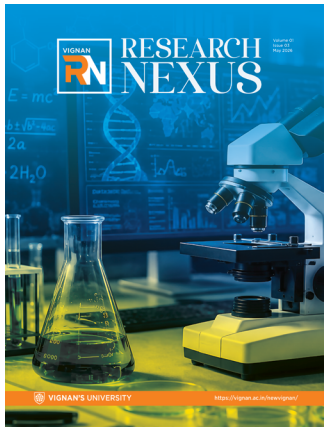

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From the Editorial Desk

Research with Purpose

This month, we present a collection of insightful research papers that reflect the evolving role of science and innovation in addressing some of society's most pressing challenges. From artificial intelligence and healthcare to sustainable energy, organic agriculture, biotechnology, and advanced materials, the studies featured in this issue demonstrate how innovation is increasingly driven by real-world needs.

What makes the research featured in this issue particularly noteworthy is its focus on creating practical impact. Whether it is developing intelligent systems that can understand human emotions, designing novel antimicrobial compounds to combat growing drug resistance, recovering valuable bioactive compounds from waste materials, or improving energy management through digital twin technologies, each study highlights the power of research to transform challenges into opportunities.

A recurring theme across these contributions is sustainability. Researchers are finding new ways to utilize natural resources efficiently, reduce waste, promote clean energy, and strengthen environmentally responsible practices. Equally important is the emphasis on human well-being, with innovations aimed at improving healthcare outcomes, enhancing agricultural productivity, and building more reliable and transparent technological systems.

The papers presented in this issue remind us that meaningful research is not confined to academic journals alone. Its true value lies in its ability to improve lives, strengthen communities, and contribute to a more sustainable future. Behind every experiment, dataset, and discovery is a commitment to solving problems and creating knowledge that serves humanity.

As you explore the articles in this edition, you will discover a rich blend of scientific excellence, interdisciplinary collaboration, and forward-thinking innovation. Together, these contributions reflect our institution's growing research culture and its dedication to advancing knowledge with purpose, relevance, and impact.

RESEARCH NEXUS

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VIGNAN RESEARCH NEXUS

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A Cascaded Ensemble Framework Using BERT and Graph Features for Emotion Detection

Dr. K. PraveenKumar, *et al.*

Poetry captures some of the deepest human emotions, yet enabling computers to understand these emotions remains a significant challenge. This research introduces an innovative artificial intelligence framework that combines language understanding, graph-based analysis, and deep learning to accurately detect emotions in English poetry. By selectively analyzing stylistic, thematic, and semantic features, the system achieves exceptional accuracy while maintaining computational efficiency. The study opens new possibilities for emotionally intelligent AI systems capable of understanding literary texts, human expression, and complex emotional communication.

Understanding the Emotional Language of Poetry

"Poetry is when an emotion has found its thought and the thought found words," observed Robert Frost. Poetry serves as a powerful medium for expressing human emotions, experiences, and perspectives. Understanding emotions embedded within poetry can provide valuable insights into human behavior, psychology, and personality. While emotion recognition has been extensively studied in social media and other textual domains, poetry remains relatively underexplored despite its rich emotional content.

Recent advances in Natural Language Processing (NLP) and deep learning have enabled the development of sophisticated models for emotion detection. However, many of these models require substantial computational resources and often suffer from overfitting, limiting their effectiveness in real-world applications. To address these challenges, this study proposes a novel Cascaded Poetic Network (CP Net) that combines BERT-based semantic representations with graph centrality features to achieve accurate and computationally efficient emotion detection from English poetry. The proposed framework achieved remarkable accuracies of 95% on the CAPEMO dataset and 98% on the BAPEMO dataset, while maintaining a computational time of only 0.274–0.332 milliseconds.

Why Smarter Feature Fusion Matters

The effectiveness of emotion recognition largely depends on how textual information is represented. Feature fusion techniques combine multiple forms of information to improve the discriminative capability of machine learning models. However, indiscriminate concatenation of features can significantly increase computational complexity without guaranteeing proportional improvements in performance.

Existing approaches often lack the ability to dynamically extract and integrate feature sets based on the requirements of individual input samples. Consequently, there remains significant scope for developing adaptive frameworks capable of performing feature fusion only when necessary. The proposed CP Net addresses this limitation by selectively extracting style, graph-based, and semantic features, thereby optimizing resource utilization while preserving classification accuracy.

Building a Cascaded Framework for Emotion Detection

To address the challenges associated with computationally intensive emotion recognition systems, the authors proposed a Cascaded Poetic Network (CP Net), a novel framework designed to improve the text representation of poetry through adaptive feature extraction and selective feature fusion. Unlike conventional approaches that process all features simultaneously, CP Net extracts and concatenates different representations of poems only when required, thereby improving the ability to capture emotions in English poetry while maintaining computational efficiency.

Consider a model M trained on a collection of sample–label pairs, where Xtrain=$\{x_1,x_2,x_3 \ldots x_n\}$ where n represents the size of the training set and Ytrain=$\{y_1,y_2,y_3 \ldots y_n\}$ is the corresponding set of labels, the goal for M is to classify x_i where x_i that is not included in training set. In this context, we define emotion classification as a multiclass classification problem. Consider a set of poems with label pairs $P=(P_i,y_i)$ where P_i is the ith poem that contains set of words i.e. $P_i=\{w_1,w_2,w_3 \ldots w_n\}$ associated with label $y_i \in$ {*happy,sad,angry,fear,surprise*} indicating poems emotion, thus emotion recognition can be seen as learning a function f:P->y. The aim is to perform emotion recognition by combining style, graph centrality and semantic features of poem based on requirement.

The proposed CP Net performs this task by combining three complementary forms of information - style features, graph centrality features, and semantic features, according to the complexity of the input poem. This adaptive strategy enables the framework to perform feature fusion only when necessary, thereby reducing computational overhead while preserving classification accuracy. Through the cascading arrangement of multiple models, the framework efficiently classifies a large proportion of poems using simpler representations and reserves more sophisticated analyses for difficult cases.

A key strength of CP Net lies in its ability to extract features on demand through three specialized modules. The first module captures Style Features, representing the structural, syntactic, and phonetic characteristics of poems. The second module extracts Graph Centrality Features, which identify the central theme of a poem by computing the

centrality scores of individual words within a graph-based representation. The third module focuses on Semantic Features, which are derived using BERT, a pre-trained contextual language model, and further processed through Bi-LSTM and Attention layers to capture deeper contextual meaning.

To integrate these feature representations effectively, the proposed framework employs a cascaded architecture consisting of three interconnected networks: the Style Feature Network (SF-Net), the Style Feature with Graph Centrality Network (SFGC-Net), and the Style Feature with Graph Centrality and Semantics Network (SFGCS-Net). The computational complexity of SF-Net and SFGC-Net is intentionally kept low compared with SFGCS-Net, enabling rapid classification of straightforward cases.

Simple multilayer perceptron networks serve as the base classifiers within the CP Net framework. Only poems that remain difficult to classify are progressively forwarded to more sophisticated stages of the architecture.

The complete design and interaction of these three networks are illustrated in Figure 1, which presents the complete architecture of the proposed Cascaded Poetic Network (CP Net). The figure highlights how style, graph centrality, and semantic representations are progressively integrated to achieve highly accurate emotion detection while optimizing computational efficiency.

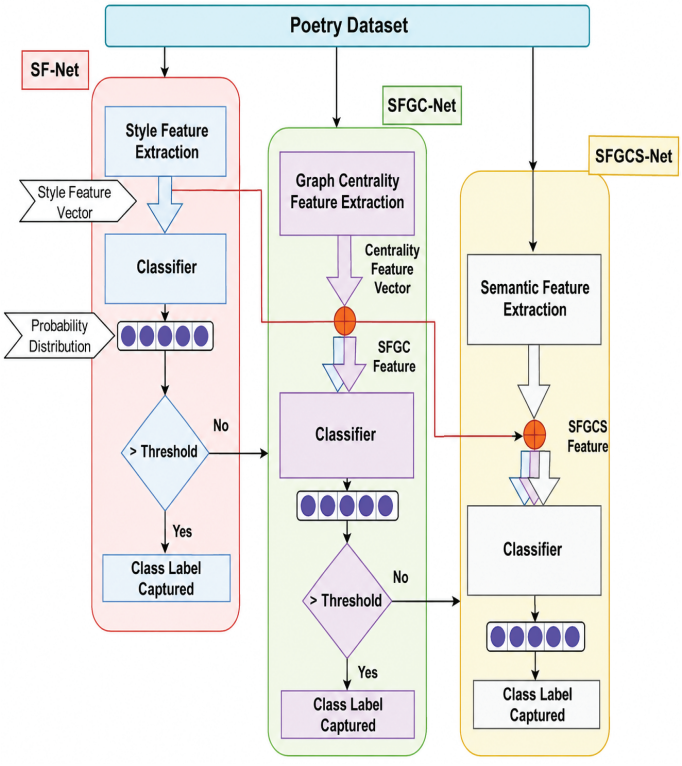

Fig 1. *Cascaded Poetic Net(CP Net) Architecture*

Innovations Driving the Proposed Framework

A major strength of the proposed Cascaded Poetic Network (CP Net) lies in its adaptive feature-fusion strategy, which enables the framework to progressively analyze poems using increasingly informative representations. This design allows the model to capture structural, thematic, and contextual information embedded within poetic language, thereby improving emotion recognition accuracy.This innovative design enables the framework to capture the structural characteristics, thematic relationships, and contextual meaning embedded within poetic language, thereby improving its ability to identify emotions accurately.

To achieve this objective, the authors developed three specialized text-classification networks that operate on different combinations of fused features and are arranged in a cascaded sequence. By progressively introducing additional information only when required, the framework maintains an optimal balance between predictive performance and computational efficiency. The study further investigates how different textual representations contribute to emotion recognition and how their selective integration enhances classification performance.

The effectiveness of the proposed framework was validated through a systematic experimental investigation using two benchmark poetry emotion datasets. The performance of CP Net was evaluated using multiple word embedding techniques, including GloVe, FastText, and BERT, enabling a comprehensive comparison of different text representation strategies for poetry emotion detection. The experimental results demonstrated the effectiveness of selective feature fusion in improving both classification performance and computational efficiency.

A Multi-Stage Journey from Words to Emotions

The operational workflow of CP Net is illustrated in Figure 2, which presents the complete functional architecture of the proposed framework. The model follows a multi-stage classification strategy in which poems are progressively analyzed using increasingly sophisticated feature representations.

In the first stage, a collection of test poems is provided as input to the Style Feature Network (SF-Net). This network extracts stylistic characteristics, including structural, syntactic, and phonetic features, and computes the probability associated with each emotional category. Since many poems can be accurately classified using stylistic information alone, this stage efficiently handles a substantial portion of the dataset while requiring minimal computational resources.

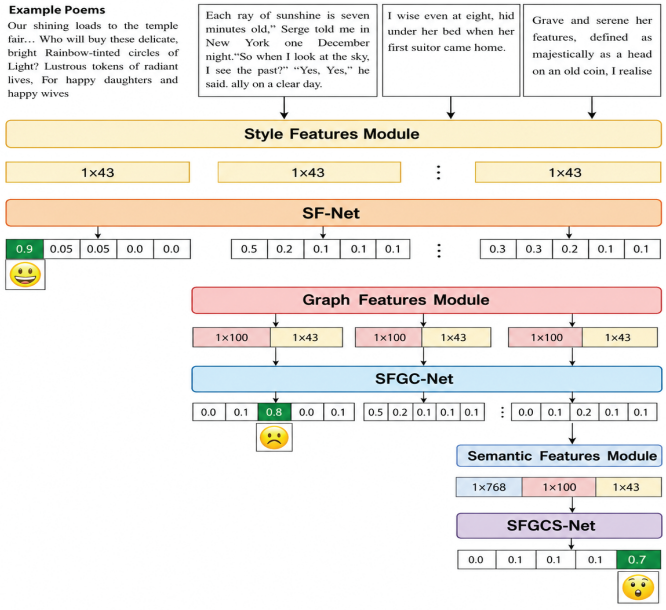

Fig 2. *Functional Architecture of Cascaded CP NET*

Following the initial classification stage, the probability scores generated by SF-Net are compared against predefined threshold values to determine whether a poem can be confidently assigned to a specific emotional category. Poems that satisfy the threshold criteria are immediately classified, enabling rapid and efficient emotion detection. However, poems for which the model cannot establish sufficient confidence are identified and forwarded to the second stage of the framework for deeper analysis.

At this stage, the Style Feature with Graph Centrality Network (SFGC-Net) comes into operation. The network extracts graph centrality features that capture the thematic importance and relationships among words within a poem. These graph-based representations are combined with the previously extracted style features to create a richer and more informative feature set. By incorporating both structural and thematic information, SFGC-Net provides a more comprehensive understanding of the poem and improves the model's ability to recognize subtle emotional expressions.

The newly generated probability scores are once again evaluated against predefined thresholds. Poems that meet the required confidence levels are assigned their corresponding emotion labels. The remaining challenging cases are then passed to the third stage of the framework, the Style Feature with Graph Centrality and Semantics Network (SFGCS-Net). This advanced module employs multiple feature extraction layers to generate detailed semantic representations using pre-trained BERT embeddings, Bi-LSTM, and Attention mechanisms. These semantic features are integrated with the style and graph centrality representations, enabling the model to capture deeper contextual meaning and complex emotional nuances present within poetic language.

By utilizing simple and computationally inexpensive feature extraction techniques during the initial stages and reserving deeper semantic analysis only for difficult cases, CP Net achieves an effective balance between computational efficiency and predictive accuracy. This selective feature-fusion strategy ensures optimal resource utilization while maintaining high-performance emotion detection across diverse poetry datasets.

Conclusion

The proposed Cascaded Poetic Network (CP Net) demonstrates how intelligent feature fusion can significantly improve emotion recognition in poetry. The framework was specifically designed to classify the majority of poems using less complex models and progressively introduce more sophisticated analyses only when necessary. Through this cascaded strategy, the model successfully combines efficiency with predictive excellence. Through its adaptive multi-stage design, CP Net successfully combines structural, thematic, and contextual information to achieve highly accurate emotion recognition in poetry. The progressive feature-fusion strategy enables the framework to effectively handle both straightforward and complex emotional expressions while maintaining efficient processing. Extensive experimental evaluation demonstrated the superiority of CP Net over four baseline models across multiple word representation techniques, including GloVe, FastText, and BERT. The results clearly indicate that the proposed framework achieves superior performance across benchmark datasets while maintaining robust classification accuracy and effective feature utilization.

The findings of this study open new avenues for research in poetry emotion analysis and explainable natural language processing. Future work may focus on identifying the most informative stylistic features through feature-selection techniques and extending the framework to multi-label classification scenarios, where a single poem can express multiple emotions simultaneously. Such advancements would further enhance the capability of intelligent systems to understand the rich emotional landscape embedded within literary texts.

Reference

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Combating Antimicrobial Resistance Through Innovative Molecular Design

Dr. Malathi Balasubramaniyan, *et al.*

Antimicrobial resistance is rapidly emerging as one of the greatest threats to global healthcare, reducing the effectiveness of many life-saving drugs. To address this challenge, researchers designed a new generation of hybrid molecules by combining pyrazoline and triazole scaffolds, two well-known bioactive chemical structures. Through computational modelling, molecular docking, and biological evaluation, several compounds demonstrated strong antibacterial and antifungal activity against clinically important pathogens. By integrating innovative molecular design with advanced drug discovery approaches, this research offers promising leads for the development of next-generation antimicrobial therapies capable of combating resistant infections and safeguarding future public health.

Unlocking New Possibilities in Antimicrobial Drug Discovery

The search for new and effective medicines often begins with the identification of molecular structures capable of interacting precisely with biological targets. Among the vast array of chemical compounds explored by medicinal chemists, nitrogen-containing heterocyclic molecules have emerged as some of the most valuable building blocks in modern drug discovery. Their unique structural features allow them to participate in a wide range of biological interactions, making them indispensable components of numerous therapeutic agents used today.

Two particularly important classes of heterocyclic compounds are pyrazolines and triazoles, both of which have attracted significant attention due to their remarkable pharmacological versatility. Pyrazolines, characterized by a five-membered ring containing two nitrogen atoms, have been extensively investigated for their broad spectrum of biological activities. Studies have demonstrated their potential as antimicrobial, anticancer, anti-inflammatory, antioxidant, analgesic, and immunosuppressive agents. In addition, several pyrazoline derivatives have shown the ability to selectively inhibit key enzymes such as cyclooxygenase-2 (COX-2) and cholinesterase, making them attractive candidates for the treatment of inflammatory disorders and neurodegenerative diseases.

Equally important are triazoles, a class of heterocyclic compounds containing three nitrogen atoms within a five-membered ring. Triazole-based molecules have established themselves as essential components in many clinically relevant drugs because of their potent antibacterial, antifungal, antiviral, and anti-inflammatory properties. Their success in medicinal chemistry stems from their exceptional chemical stability and their ability to form strong interactions with biological targets, enabling effective inhibition of pathogenic microorganisms and disease-related enzymes.

The therapeutic potential of both pyrazolines and triazoles arises from their capacity to interact efficiently with proteins, nucleic acids, and other biomolecules through hydrogen bonding, electrostatic interactions, and hydrophobic forces. These molecular interactions play a critical role in determining biological activity and often influence the effectiveness of a drug candidate. Consequently, researchers have increasingly explored strategies to combine multiple bioactive scaffolds within a single molecular framework to achieve enhanced therapeutic performance as shown in Fig 1.



Fig 1: *Biomedidical Applications of pyrazolines*

One promising approach involves the development of hybrid molecules, in which two pharmacologically active structural units are integrated into a single compound. Such hybridization strategies aim to combine the beneficial properties of both scaffolds, potentially leading to improved potency, selectivity, and pharmacokinetic behaviour. In recent years, hybrid heterocyclic compounds have emerged as powerful tools in drug discovery, particularly in the search for novel antimicrobial agents capable of addressing the growing challenge of drug resistance.

Building upon this concept, the present study focuses on the design and evaluation of a new series of pyrazoline–triazole hybrid molecules. By integrating two well-established

pharmacophores into a single molecular architecture, the research seeks to identify novel bioactive compounds with enhanced antimicrobial potential. Through a combination of computational screening, molecular docking studies, biological evaluation, and pharmacokinetic assessment, this work aims to contribute to the development of next-generation therapeutic agents capable of combating emerging microbial threats and supporting future advances in antimicrobial drug discovery.

The Growing Threat of Antimicrobial Resistance

Antimicrobial resistance (AMR) has emerged as one of the most pressing healthcare challenges of the modern era, threatening the effectiveness of many life-saving antibiotics that have transformed medical practice over the past century. As microorganisms are repeatedly exposed to antimicrobial agents, they continuously evolve strategies to survive, rendering conventional treatments less effective. This growing resistance has led to an alarming increase in difficult-to-treat infections, prolonged hospital stays, and rising healthcare costs worldwide.

The rapid spread of resistant bacterial and fungal pathogens has created an urgent need for innovative therapeutic solutions. Existing antimicrobial drugs are gradually losing their ability to combat emerging infections, highlighting the necessity for new molecules that not only exhibit strong biological activity but also possess favorable pharmacokinetic properties such as improved absorption, stability, and safety. Developing such next-generation therapeutics has become a major focus of contemporary medicinal chemistry research.

Among the diverse classes of bioactive molecules, pyrazolines and triazoles have attracted considerable attention due to their broad spectrum of pharmacological activities. However, despite their promising therapeutic potential, their individual effectiveness may be limited by resistance-related challenges and suboptimal drug-like characteristics. To address these limitations, researchers are increasingly exploring hybrid molecular designs that combine the strengths of both scaffolds into a single structure. Such hybrid compounds offer exciting opportunities for developing more potent and effective antimicrobial agents capable of addressing the growing global threat of antimicrobial resistance.

Charting a New Path in Antimicrobial Discovery

To address the growing challenge of antimicrobial resistance, this study focused on the design, synthesis, and evaluation of a series of novel pyrazoline-triazole hybrid compounds (14–25) as potential antimicrobial agents. The research was driven by the hypothesis that combining two pharmacologically important heterocyclic scaffolds within a single molecular framework could enhance biological activity while improving drug-like characteristics as shown in Fig 2. Through an integrated approach involving computational screening, chemical synthesis, biological evaluation, and pharmacokinetic assessment, the study sought to identify promising candidates capable of combating resistant microbial pathogens.

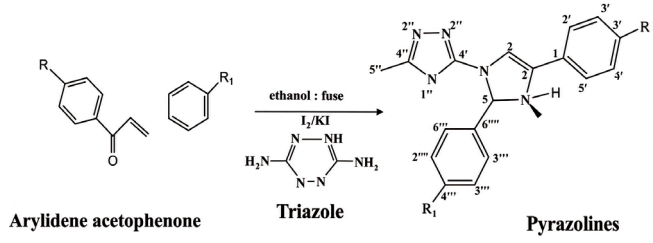

Fig 2: *Synthesis of pyrazolines*

A systematic multidisciplinary strategy was adopted to investigate the therapeutic potential of these hybrid molecules. The compounds were synthesized through carefully designed reactions involving substituted ketones and aldehydes, followed by cyclization to generate the desired pyrazoline derivatives. Structural confirmation of the synthesized compounds was achieved using a range of analytical techniques, including Infrared (IR) spectroscopy, Mass spectrometry, and Nuclear Magnetic Resonance (NMR) spectroscopy, complemented by advanced two-dimensional NMR analyses to ensure structural accuracy and purity.

To accelerate the discovery process and gain molecular-level insights into biological activity, computational studies were performed using state-of-the-art molecular modelling tools. Ligand structures were designed and optimized, while the three-dimensional structures of bacterial target proteins were obtained from the Protein Data Bank. Molecular docking studies were subsequently carried out using AutoDock Vina to investigate the interaction of the synthesized compounds with two clinically important bacterial enzymes, DNA gyrase and topoisomerase IV, both of which play essential roles in DNA replication and cell survival. In parallel, ADMET prediction tools, including SwissADME and ProTox-II, were employed to evaluate pharmacokinetic properties, drug-likeness, and toxicity profiles, providing an early assessment of their suitability as potential therapeutic agents.

Discovering the Most Promising Antimicrobial Candidates

The molecular docking investigations revealed highly encouraging results, with all synthesized compounds demonstrating strong binding affinity toward bacterial

DNA gyrase and topoisomerase IV. Several compounds exhibited binding energies comparable to, and in some cases superior to, those of the standard antibacterial drug ciprofloxacin. Detailed interaction analyses showed the formation of stable hydrogen bonds and hydrophobic interactions within the active sites of the target enzymes, suggesting an effective mechanism for inhibiting microbial DNA replication and growth.

The computational findings were further validated through in vitro antimicrobial studies against a range of clinically relevant bacterial pathogens, including *Escherichia coli, Pseudomonas aeruginosa,* and *Staphylococcus aureus,* as well as fungal strains such as *Aspergillus niger* and *Rhizopus*. Among the synthesized compounds, compound 23 emerged as the most potent antibacterial candidate, exhibiting a minimum inhibitory concentration (MIC) of 6.25 µg/mL against Pseudomonas aeruginosa. Notably, compounds containing halogen substituents, particularly fluorine, chlorine, and bromine, displayed significantly enhanced antimicrobial activity, highlighting the beneficial influence of electron-withdrawing groups on biological performance.

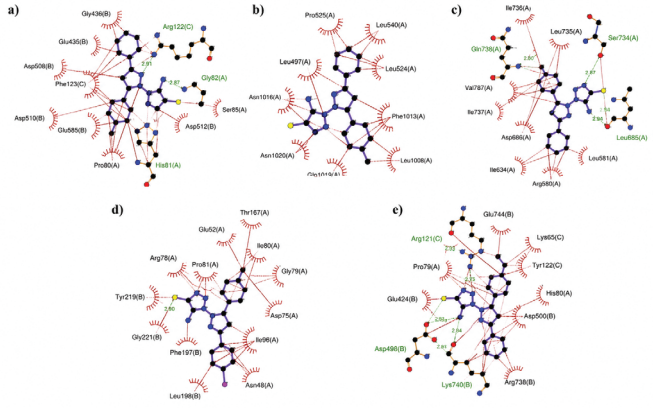

Fig 3: *a) Binding Interactions of compound 19 with 5CDP (DNA Gyrase of Staphylococcus aureus), b) Binding interactions of compound 19 with 5EIX (DNA Topoisomerase IV of Klebsiella pneumonia), c) Binding interactions of compound 17 with 5ZTJ (DNA GyraseA of S.typhi), (d) Binding interactions of compound 18 with 6MIJ (DNA Gyrase of Pseudomonas aeruginosa) and (e) Binding interactions of compound 25 with 6RKW (DNA Gyrase of E.coli).*

The antifungal investigations also produced promising outcomes. Compounds 21, 22, and 23 demonstrated notable activity against fungal pathogens, with compound 22 exhibiting particularly strong inhibition of Aspergillus niger and Rhizopus species at a concentration of 12.5 µg/mL. Structure-activity relationship (SAR) analysis revealed that molecular substituents play a decisive role in determining antimicrobial efficacy. The observed activity trend, Cl > F > Br > OCH_3 > CH_3, clearly demonstrated that electron-withdrawing substituents significantly enhance biological performance and may serve as valuable design elements for future antimicrobial agents.

Beyond their antimicrobial potency, the synthesized compounds also exhibited favorable pharmacokinetic characteristics. ADMET analysis indicated high gastrointestinal absorption, good skin permeability, compliance with established drug-likeness criteria, and moderate toxicity profiles as shown in Fig 2. These properties suggest that the developed pyrazoline–triazole hybrids possess the necessary attributes for further preclinical investigation and optimization.

Conclusion

The present study successfully demonstrates the potential of pyrazoline-triazole hybrid molecules as promising antimicrobial candidates. The combined application of chemical synthesis, molecular docking, biological evaluation, structure-activity relationship analysis, and ADMET prediction provided a comprehensive assessment of their therapeutic potential. Among the synthesized compounds, compound 23 emerged as the most effective antibacterial agent, while compound 22 showed particularly promising antifungal activity. The enhanced performance observed in halogen-substituted derivatives further emphasizes the importance of rational molecular design in optimizing biological activity.

Collectively, these findings highlight the significant promise of hybrid heterocyclic compounds in the development of next-generation antimicrobial therapies. By integrating complementary pharmacological features within a single molecular scaffold, these compounds offer a promising strategy for overcoming the limitations of existing drugs and addressing the escalating global challenge of antimicrobial resistance.

Reference

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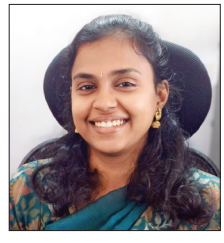

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A digital twin framework driven energy management strategy for hybrid DC microgrids with integrated xEV charging applications

Dr. A. R. Vijay Babu, *et al.*

As renewable energy systems and electric vehicle charging networks continue to expand, intelligent energy management has become essential for building reliable smart grids. This research introduces a Digital Twin-driven framework that combines IoT monitoring, machine learning, and adaptive control to optimize power flow in hybrid DC microgrids. By creating a real-time virtual replica of the physical system, the framework enables anomaly detection, predictive maintenance, and efficient energy utilization. The proposed approach enhances system reliability, reduces energy wastage, and supports the development of sustainable, resilient, and future-ready energy infrastructure.

Powering the Future with Intelligent Energy Management

The current energy environment has changed due to the quick development of renewable energy systems and electric vehicle (xEV) charging infrastructure. Future smart grids will require hybrid DC microgrids that incorporate solar photovoltaic systems, wind turbines, battery energy storage, and intelligent charging stations. However, issues including missing sensor data, communication breakdowns, hacks, and imprecise measurements are brought about by the growing reliance on IoT-based monitoring.

This paper proposes an integrated Digital Twin (DT) framework for intelligent energy management in hybrid DC microgrids that combines Machine Learning (ML) and an Adaptive Neuro-Fuzzy Inference System (ANFIS) controller. For dependable and effective system operation, the suggested framework permits real-time monitoring, anomaly detection, predictive analysis, and adaptive control.

Digital Twin Assisted Smart Energy Management

The suggested architecture uses Digital Twin technology to produce a synchronized virtual copy of the physical microgrid. To find anomalous operating situations, real-time IoT data gathered from solar PV systems, wind turbines, battery storage units, and xEV charging stations is constantly compared with predictions produced by DT.

Under both normal and disturbed circumstances, the DT platform facilitates intelligent decision-making, defect diagnosis, and predictive simulations. To increase overall system reliability, identify abnormalities, and approximate missing data, machine learning techniques are used. To guarantee steady energy management, the ANFIS controller dynamically controls power flow, battery charging and discharging, and load balancing.

The overall architecture of the proposed Digital Twin-assisted energy management framework, including renewable energy sources, battery storage, IoT monitoring, machine learning-based anomaly detection, and ANFIS control, is illustrated in Figure 1.

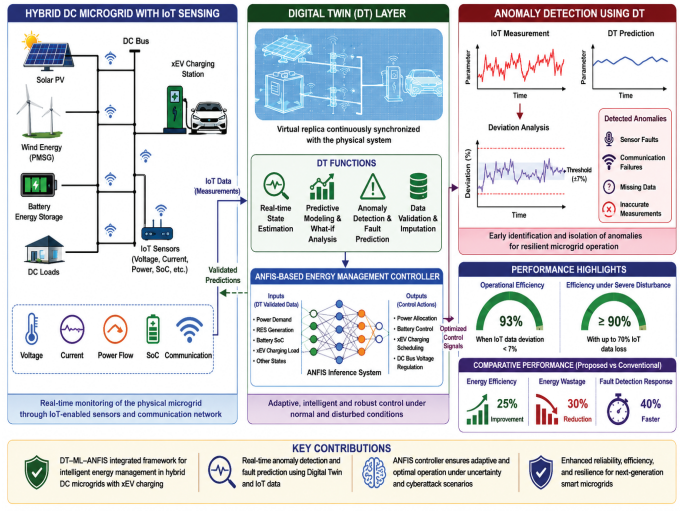

Fig 1. *Digital Twin-assisted intelligent energy management framework for IoT-enabled hybrid DC microgrids with integrated xEV charging infrastructure.*

Integration of Renewable Energy Sources

To provide sustainable power generation, the hybrid DC microgrid combines wind turbine systems with solar photovoltaic arrays. Wind turbines supplement the energy supply in different atmospheric conditions, whereas solar PV systems provide the most power throughout the day.

In order to store excess renewable energy and provide power when renewable generation is low, battery energy storage systems are essential. Effective battery charging and discharging activities are made possible by a bidirectional DC-DC converter, which raises the system's overall dependability and efficiency.

IoT Monitoring and Missing Data Handling

Within the microgrid, IoT sensors continuously track voltage, current, power flow, solar radiation, wind speed, and battery state of charge (SoC). However, missing or incorrect data might be caused by environmental disruptions, sensor faults, and communication breakdowns.

The Digital Twin framework uses regression-based estimating methods and interpolation to forecast missing data in order to get around this restriction. Any departures from the predetermined threshold are considered anomalies when the DT-generated outputs are compared against IoT measurements. Operational resilience and data reliability are greatly increased by this procedure.

Machine Learning and ANFIS-Based Control

The Digital Twin platform incorporates machine learning approaches to enhance intelligent control and prediction accuracy. Faulty measurements, unusual system behavior, and cyberattack scenarios are all identified by the proposed system using ML-driven anomaly detection.

Neural network learning and fuzzy logic reasoning are combined in the Adaptive Neuro-Fuzzy Inference System (ANFIS) controller. Under various operating conditions, this adaptive controller dynamically controls the allocation of renewable energy, battery functioning, and xEV charging needs.

Performance Evaluation and Key Outcomes

Simulation studies demonstrate that the proposed DT–ML–ANFIS framework achieves significant improvements in energy management performance. The system maintains approximately 93% operational efficiency when IoT data deviations remain below 7%, and sustains nearly 90% efficiency even during severe disturbances with up to 70% data loss.

Comparative analysis indicates approximately:

- 25% improvement in energy efficiency.
- 30% reduction in energy wastage
- 40% faster fault detection response

The results confirm that Digital Twin technology combined with machine learning can substantially enhance reliability, predictive maintenance capability, and intelligent decision-making in next-generation hybrid microgrids.

Conclusion

In hybrid DC microgrids with xEV charging infrastructure, this work shows how Digital Twin technology, IoT sensing, machine learning, and ANFIS-based adaptive control may be successfully integrated for intelligent energy management.

Under dynamic operating situations, the suggested framework enhances system resilience, fault tolerance, energy optimization, and operational stability. The Digital Twin platform facilitates anomaly detection, predictive maintenance, and sustainable energy management by allowing real-time synchronization between physical and virtual systems. For upcoming smart grids, renewable energy systems, and intelligent transportation infrastructure, the established technique provides a scalable and dependable solution.

Reference

Saleha Tabassum, Attuluri R Vijay Babu, Dharmendra Kumar Dheer, Rajanand Patnaik Narasipuram (2026). A digital twin framework driven energy management strategy for hybrid DC microgrids with integrated xEV charging applications. Sustainable Computing: Informatics and Systems, 51, 101364.



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Cobalt Embedded N-Doped Carbon Spheres Derived From Cassava Starch for Enhanced Oxygen Reduction Reaction in Alkaline Medium

Dr. Habibuddin Shaik, *et al.*

The transition to clean energy technologies demands efficient and affordable catalysts for fuel cells and metal-air batteries. In this study, cobalt embedded nitrogen-doped carbon spheres were developed using cassava starch, a renewable biomass resource, as a sustainable alternative to costly platinum-based catalysts. The resulting material demonstrated excellent oxygen reduction activity, remarkable durability, and superior methanol tolerance in alkaline media. By transforming an agricultural resource into a high-performance electrocatalyst, this work offers a promising pathway toward low-cost, environmentally friendly energy conversion and storage technologies.

Overview

This research presents the development of a sustainable and cost-effective non-noble metal electrocatalyst for the oxygen reduction reaction (ORR) in alkaline media. The study focuses on synthesizing cobalt embedded nitrogen-doped carbon spheres (Co-N-C/CS) using cassava starch as a biomass-derived carbon precursor. The catalyst was designed to replace expensive platinum-based catalysts commonly used in fuel cells and metal-air batteries.

Background

Fuel cells and metal-air batteries require highly efficient ORR catalysts. Platinum catalysts offer excellent performance but suffer from high cost, scarcity, and poor long-term durability. Researchers are therefore investigating biomass-derived carbon materials combined with transition metals such as cobalt to improve catalytic performance while reducing cost.

Methodology

Cassava starch extracted from cassava roots was hydrothermally processed and pyrolyzed at 800°C to obtain carbon spheres. Nitrogen doping was introduced using melamine, and cobalt incorporation was achieved using cobalt chloride precursor. Structural and electrochemical characterization techniques including XRD, Raman spectroscopy, XPS, FESEM, HRTEM, BET surface area analysis, cyclic voltammetry, and rotating disk electrode studies were carried out for further analysis. Figure 1 shows the FESEM image of Carbon spheres synthesized with various dopants.

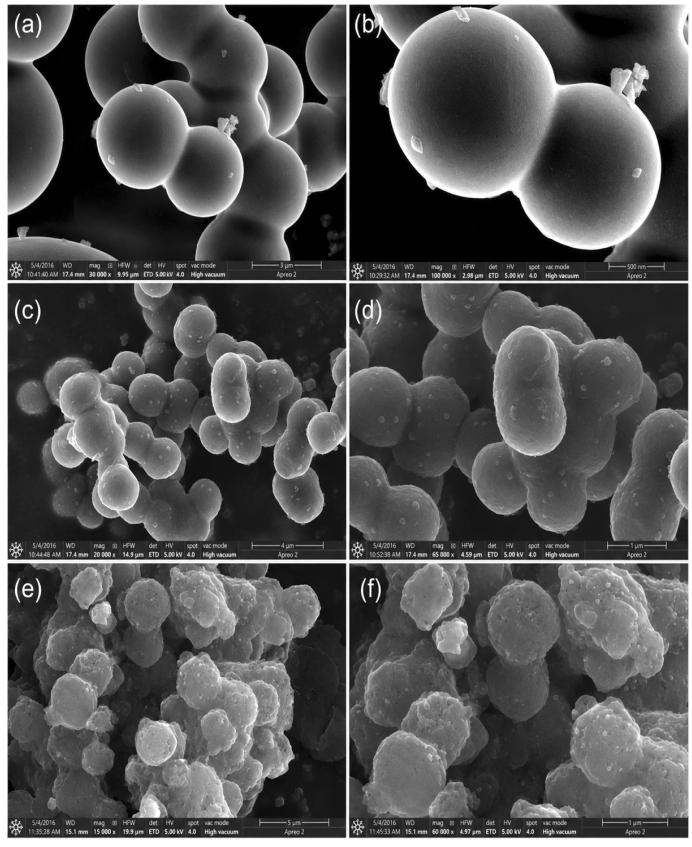

Fig 1: *FESEM images of C -CS (a,b), NC -CS (c,d), and Co -N -C/CS (e,f).*

As shown in Figure 2, the catalysts display a well-defined O2 reduction peak in the oxygen-saturated 0.1 M KOH (solid line), yet it is absent in the nitrogen-saturated (dash- dot line) electrolyte. The reduction peak potential, a measure of the

catalytic performance, was also inspected, and it is more positive for the Co -N -C/CS (0.82 V vs RHE) compared to the other samples, NC -CS (0.78 V vs RHE) and C -CS (0.58 V vs RHE). This indicates the superior ORR activity of Co -N -C/CS

Key Results

The synthesized Co-N-C/CS catalyst demonstrated remarkable ORR performance. The material exhibited a limiting current density of ₹4.64 mA cm-2 with an onset potential of 0.91 V (vs RHE). The calculated electron transfer number of 3.74 confirmed the dominant four-electron ORR pathway, comparable to commercial Pt/C catalysts.

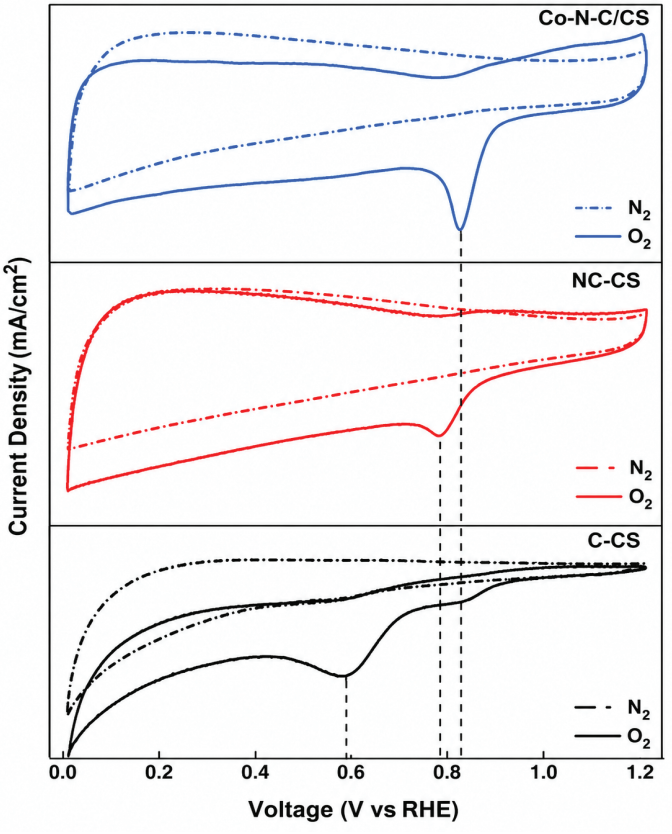

Fig 2: *CV plots of C-CS, NC-CS, and Co-N -C/CS in N2 (dash-dot line) and O2 (solid line) saturated 0.1 M KOH electrolyte at a scan rate of 20 mV s- 1*

Stability and durability

The catalyst showed excellent durability with 99% current retention after 14,000 seconds of operation in alkaline electrolyte. Methanol crossover resistance studies also indicated superior tolerance compared to commercial Pt/C catalysts, making the material highly suitable for direct methanol fuel cells.

Research Significance

The incorporation of cobalt and nitrogen into the porous carbon framework significantly increased active catalytic sites and enhanced oxygen adsorption. The use of cassava starch as a sustainable biomass precursor demonstrates an environmentally friendly approach for producing advanced electrocatalysts.

Conclusion

This work successfully demonstrates a highly efficient biomass-derived Co-N-C electrocatalyst with excellent ORR activity, durability, and methanol tolerance. The study highlights the potential of low-cost sustainable materials for next-generation clean energy technologies and offers an effective alternative to platinum-based catalysts.

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Green Recovery of Omega-3-Rich Lipids from Fish Viscera and Their Biological Validation

Dr. N. S. Sampath Kumar, *et al.*

Fish-processing industries generate large quantities of waste, much of which remains underutilized despite being rich in valuable biomolecules. This research demonstrates a sustainable approach for recovering omega-3-rich lipids from fish viscera using green extraction technologies and selective enrichment methods. The recovered lipids exhibited strong antioxidant, antimicrobial, anti-inflammatory, and wound-healing properties, confirming their potential for nutraceutical and biomedical applications. By transforming aquaculture waste into high-value bioactive products, the study advances circular bioeconomy principles while promoting sustainable resource utilization and environmental stewardship

Transforming Aquaculture Waste into High-Value Bioactive Resources

The global expansion of aquaculture has played a pivotal role in addressing the increasing demand for affordable and nutritious protein sources. However, alongside this growth, the fish-processing sector generates substantial quantities of by-products that remain largely underutilized. Depending on the species and processing practices, nearly 30–70% of the harvested biomass may be discarded as waste. Among these by-products, fish viscera represent a particularly valuable yet overlooked resource owing to their richness in lipids, proteins, digestive enzymes, and other biologically active molecules.

Traditionally, fish viscera are discarded or sold at negligible prices, creating environmental concerns while simultaneously resulting in the loss of potentially valuable biomolecules. The development of sustainable technologies capable of recovering high-value compounds from these waste streams is therefore becoming increasingly important in the context of circular bioeconomy and sustainable biotechnology.

Recognizing this opportunity, our research focused on the valorization of Catla catla viscera, a major fish-processing by-product generated from one of India's most extensively cultured freshwater fish species. The study aimed to develop an environmentally sustainable strategy for recovering omega-3-rich lipids and to evaluate their biological functionality for potential nutraceutical and biomedical applications.

A Sustainable Approach for Lipid Recovery

Fish-derived omega-3 fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), are widely recognized for their antioxidant, anti-inflammatory, cardioprotective, neuroprotective, and wound-healing properties. Although marine fish remain the primary commercial source of these compounds, freshwater aquaculture species offer a promising and sustainable alternative.

To maximize lipid recovery from Catla catla viscera, multiple extraction strategies were comparatively evaluated, including conventional solvent extraction, ultrasound-assisted extraction, and autoclave-assisted extraction. Among these methods, autoclave-assisted extraction produced the highest crude lipid recovery (16%), while the classical Bligh and Dyer extraction method generated a more nutritionally balanced fatty acid profile enriched with biologically important polyunsaturated fatty acids.

Importantly, the conventional extraction system relies on chloroform and methanol, solvents associated with environmental and occupational safety concerns. To address this challenge, the study incorporated green chemistry principles through the replacement of these solvents with ethanol and 2-methyltetrahydrofuran (2-MeTHF), both of which are considered environmentally benign and renewable alternatives. The resulting green-solvent extraction system-maintained extraction efficiency while simultaneously enhancing sustainability, thereby providing a practical route for environmentally responsible lipid recovery.

From Waste to Omega-3-Rich Lipids

Gas Chromatography-Flame Ionization Detection (GC-FID) analysis revealed that the recovered lipids contained nutritionally significant levels of long-chain omega-3 fatty acids. The conventional extraction method yielded a total PUFA content of 28.44%, including 20.16% omega-3 fatty

acids, with EPA and DHA concentrations of 9.47% and 6.81%, respectively.

Further optimization through green-solvent extraction increased total PUFA content to 35.20% while maintaining a favorable omega-3 profile. These findings demonstrate that sustainable extraction technologies can successfully recover nutritionally valuable lipid fractions without sacrificing product quality.

Selective Enrichment of Polyunsaturated Fatty Acids

While crude lipid extracts contain a mixture of saturated, monounsaturated, and polyunsaturated fatty acids, the nutritional and therapeutic value of the lipid fraction can be substantially enhanced through selective concentration of PUFAs.

To achieve this objective, the recovered lipids were subjected to urea complexation, a simple and scalable technique widely used for the enrichment of unsaturated fatty acids. Different urea-to-free fatty acid ratios were evaluated to identify conditions that maximize omega-3 concentration.

The results demonstrated a remarkable enrichment effect. At an optimized urea-to-fatty acid ratio of 6:1, total PUFA content increased from 28.44% to 56.03%, while omega-3 fatty acids increased from 20.16% to 49.86%. This nearly two-fold enhancement highlights the efficiency of the developed process and demonstrates its potential for producing nutritionally superior lipid concentrates from fish-processing by-products.

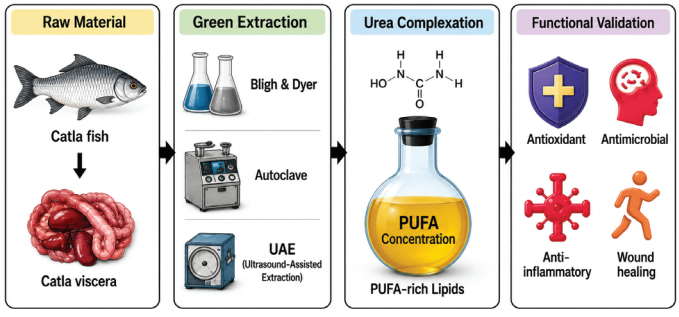

Fig 1: *Sustainable valorization of Catla catla viscera into PUFA-rich bioactive lipids.*

Fish viscera were converted into omega-3-rich lipid concentrates through green extraction and urea complexation. The enriched lipid fractions exhibited antioxidant, antimicrobial, anti-inflammatory, and wound-healing activities, demonstrating the transformation of aquaculture waste into high-value bioactive products (Figure 1).

Functional Validation of the PUFA-Enriched Fraction

The true value of recovered lipids lies not only in their composition but also in their biological functionality. Therefore, the omega-3-enriched fractions were subjected to a comprehensive series of in vitro biological evaluations.

Potent Antioxidant Activity

Oxidative stress is implicated in numerous chronic diseases, including cardiovascular disorders, neurodegeneration, and inflammatory conditions. The PUFA-enriched fraction exhibited strong free-radical scavenging activity in DPPH assays, achieving more than 60% scavenging at low concentrations and demonstrating an IC_{50} below 0.2 mg mL^{-1}. These findings indicate substantial antioxidant potential and highlight the capacity of the enriched fraction to neutralize reactive oxygen species.

Antibacterial Potential

The antimicrobial properties of the recovered lipids were evaluated against representative bacterial pathogens. The PUFA-enriched fraction exhibited significantly improved antibacterial activity compared with crude lipid extracts, particularly against Staphylococcus aureus and Pseudomonas aeruginosa. The enhanced activity observed following PUFA enrichment suggests that omega-3 fatty acids contribute substantially to the antimicrobial properties of the lipid fraction.

Cytocompatibility and Safety

For any potential biomedical or nutraceutical application, biological safety is of paramount importance. Cytotoxicity studies performed using human keratinocyte and macrophage cell lines demonstrated excellent biocompatibility, with cell viability remaining above 80% across the tested concentration range. The absence of significant cytotoxic effects confirms the suitability of the enriched lipid fraction for further therapeutic exploration.

Enhanced Wound-Healing Activity

One of the most promising findings of this study was the ability of the PUFA-enriched fraction to promote wound repair. Using an in vitro scratch wound model, the enriched fraction achieved approximately 79% wound closure, outperforming the crude lipid extract and demonstrating enhanced cellular migration and regenerative activity.

These observations support the growing body of evidence suggesting that omega-3 fatty acids play important roles in tissue regeneration, cell signaling, and wound healing processes.

Anti-Inflammatory and Immunomodulatory Effects

Inflammation is a critical component of tissue repair; however, prolonged or excessive inflammatory responses can delay healing and contribute to chronic disease progression. To evaluate the immunomodulatory potential of the enriched lipid fraction, inflammatory responses were assessed in lipopolysaccharide-stimulated macrophages.

Treatment with the omega-3-rich fraction produced a pronounced reduction in the pro-inflammatory cytokine TNF-α while simultaneously increasing the production of the anti-inflammatory mediator TGF-β1. At the highest concentration tested, TNF-α levels decreased to 112.68 pg/mL, whereas TGF-β1 levels increased to 571.52 pg/mL. This dual action demonstrates the ability of the enriched fraction to modulate inflammatory pathways and promote a favorable healing environment.

Advancing Circular Bioeconomy Through Waste Valorization

Beyond its scientific contributions, this work represents a practical example of circular bioeconomy in action. Rather than treating fish viscera as a disposal problem, the study demonstrates how this underutilized biomass can be transformed into a source of high-value bioactive compounds with applications in health, nutrition, and biotechnology.

The technologies employed are relatively simple, economically feasible, and require only modest infrastructure, making them potentially suitable for implementation at fish-processing facilities and small-scale industrial units. Such an approach could simultaneously reduce environmental burdens, generate additional revenue streams, and support sustainable aquaculture practices.

The recovered omega-3-rich fractions hold considerable promise for applications in:

- Nutraceutical formulations
- Functional foods
- Dietary supplements
- Wound-healing products
- Biomedical formulations
- Anti-inflammatory therapeutics

Conclusion

This study successfully establishes Catla catla viscera as a valuable source of omega-3-rich bioactive lipids and demonstrates an integrated strategy for their sustainable recovery, enrichment, and functional validation. By combining green-solvent extraction with urea complexation, substantial enhancement of polyunsaturated fatty acid content was achieved while preserving important biological activities.

The work exemplifies how biotechnology can transform low-value aquaculture waste into high-value health-promoting products, contributing simultaneously to resource sustainability, waste reduction, and economic value creation. As the global emphasis on circular bioeconomy continues to grow, such approaches offer promising pathways toward more sustainable and resource-efficient food production systems.

Reference

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Bringing Transparency to Data Extraction in Computational Social Systems

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Every day, vast amounts of data are generated through healthcare systems, social media platforms, businesses, and scientific research. Yet one of the greatest challenges of modern artificial intelligence is not simply making predictions, but understanding how those predictions are made. To address this challenge, researchers developed an innovative explainable machine learning framework that combines swarm intelligence, feature clustering, and optimization techniques to identify the most informative data attributes while reducing computational complexity. By making machine learning systems more transparent, efficient, and trustworthy, this research has the potential to improve decision-making across critical sectors such as healthcare, cybersecurity, social analytics, and business intelligence.

Making Sense of Complex and Diverse Data

The rapid growth of digital technologies has generated enormous volumes of data across healthcare, social networks, business systems, education, and scientific research. Extracting meaningful insights from these diverse datasets remains one of the most significant challenges in modern artificial intelligence. While machine learning algorithms have demonstrated remarkable success in prediction and classification tasks, understanding which features contribute most to decision-making remains equally important. This has led to the emergence of Explainable Machine Learning (XML), a field focused on improving transparency, interpretability, and trust in intelligent systems.

Feature selection plays a crucial role in explainable machine learning by identifying the most informative attributes while eliminating redundant or irrelevant information. However, many existing feature selection techniques are designed for specific datasets and often fail to perform consistently across diverse data environments. Developing a common framework capable of handling datasets with varying characteristics, dimensions, and complexities therefore remains a challenging research problem.

To address this challenge, the present study proposes a comprehensive feature selection framework that integrates multiple computational approaches, including Particle Swarm Optimization (PSO), global and local search strategies, feature ranking, feature clustering, computational cost-based feature selection, and multi-objective optimization. The framework focuses on balancing three critical objectives: maximizing classification accuracy, minimizing the number of selected features, and reducing computational cost. Through extensive experimentation on diverse datasets, the proposed framework demonstrates its ability to achieve high predictive performance while maintaining computational efficiency and model interpretability.

Building Smarter Pathways for Data Understanding

Although numerous feature selection approaches have been developed over the years, most are tailored to specific applications or datasets. As a result, their performance often varies when applied to data with different characteristics. The proposed framework addresses this limitation by integrating multiple complementary feature selection strategies into a unified architecture capable of adapting to diverse datasets. By combining optimization, ranking, clustering, and cost-sensitive evaluation techniques, the framework provides a more generalized solution for feature selection and classification tasks.

Learning from Nature: The Power of Swarm Intelligence

Nature has long inspired solutions to complex computational problems. One such example is Particle Swarm Optimization (PSO), a powerful optimization technique inspired by the collective behavior of bird flocks and fish schools. In these natural systems, individuals cooperate and share information to locate optimal resources efficiently. Similarly, PSO employs a population of particles that continuously adjust their positions within a search space to identify optimal solutions.

Within the proposed framework, PSO serves as the foundation for selecting informative feature subsets. Each particle represents a potential solution and updates its position based on both its personal best experience and the best solution identified by the swarm. Through iterative optimization, the algorithm searches for feature combinations that maximize classification accuracy while

reducing redundancy and computational complexity.

$$v_{id}^{t+1} = w * v_{id}^{t} + c_1 * r_{i1} * (p_{id} - x_{id}^{t}) + c_2 * r_{i2} * (p_{gd} - x_{id}^{t}) \quad (1)$$

$$x_{id}^{t+1} = x_{id}^{t} + v_{id}^{t+1} \quad (2)$$

$$I(f_i; c) = -\sum_{i \in |F|} p(f_i, c) log_2 \frac{p(f_i,c)}{p(f_i)p(c)} \quad (3)$$

$$Rel(F) = \sum_{f_i \in F} I(f_i; c) \quad (4)$$

$$\Delta Rel(f_i) = I(f_i; c) \quad (5)$$

$$Red(F) = \sum_{f_i, f_j \in F} I(f_i, f_j) \quad (6)$$

$$\Delta Red(f_i) = \sum_{f_i, f_j \in F; f_i \neq f_j} I(f_i, f_j) \quad (7)$$

$$B(f_i) = \Delta Rel(f_i - \frac{1}{|F|-1} \Delta Red(f_i)) \quad (8)$$

$$B'(f_i) = \frac{1}{x_i} * (\Delta Rel(f_i) - \frac{1}{|F|-1} \Delta Red(f_i)) \quad (9)$$

Eliminating Redundancy for Better Decision-Making

One of the major challenges in feature selection is identifying and removing redundant information without compromising predictive performance. The proposed framework incorporates a Backward Elimination (BE) strategy based on mutual information analysis to evaluate both feature relevance and redundancy.

By systematically eliminating features that contribute little useful information while retaining those most relevant to classification, the approach improves model efficiency and interpretability. The integration of filter-based evaluation with PSO optimization enables the framework to benefit from both computational efficiency and high classification performance.

Balancing Accuracy and Computational Efficiency

Achieving high classification accuracy often requires evaluating large numbers of features, resulting in increased computational cost. The proposed Backward Elimination strategy addresses this challenge by dynamically selecting features based on optimization outcomes while preserving critical information required for accurate prediction.

The framework performs elimination at the cluster level, ensuring that important features remain available even when redundant attributes are removed. This strategy substantially reduces computational overhead without compromising model performance. The overall workflow of the Backward Elimination strategy adopted in the proposed framework is illustrated in Figure 1.

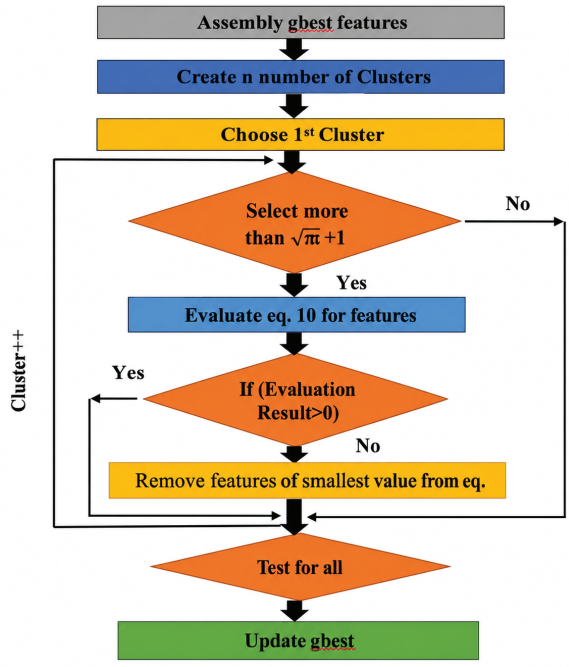

Fig 1. *Process of Backward Elimination (BE)*

Organizing Complex Data Through Feature Clustering

Large datasets frequently contain groups of highly correlated features that provide similar information. Processing all such features unnecessarily increases computational burden and may negatively impact model interpretability.

To address this issue, the proposed Structured Feature Ranking (SFR) approach organizes features into disjoint clusters based on their relationships and correlations. Features are then ranked within each cluster, enabling the selection of representative attributes while minimizing redundancy. This structured ranking strategy improves feature diversity and enhances overall classification performance. The architecture of the Structured Feature Ranking approach and the interaction between feature clustering and ranking processes are presented in Figure 2

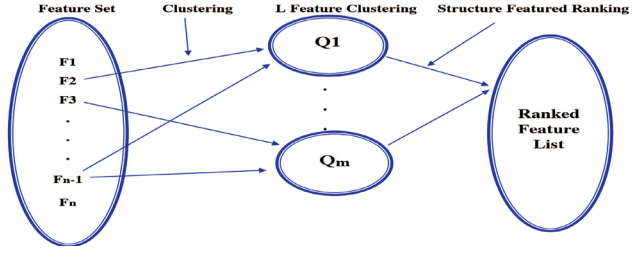

Fig 2. *Process of Structured Feature Ranking Method*

Reducing Cost Without Compromising Performance

Beyond predictive accuracy, practical machine learning applications must also consider computational cost. Feature evaluation, data collection, and processing expenses can significantly influence the feasibility of real-world implementations.

To balance these competing objectives, the framework incorporates Cost-Sensitive Correlation-Based Feature Selection (CS-CFS). This approach evaluates both classification performance and feature acquisition costs, enabling the selection of feature subsets that provide maximum predictive value at minimal cost. The complete wrapper framework used for cost-sensitive feature selection and evaluation is depicted in Figure 3.

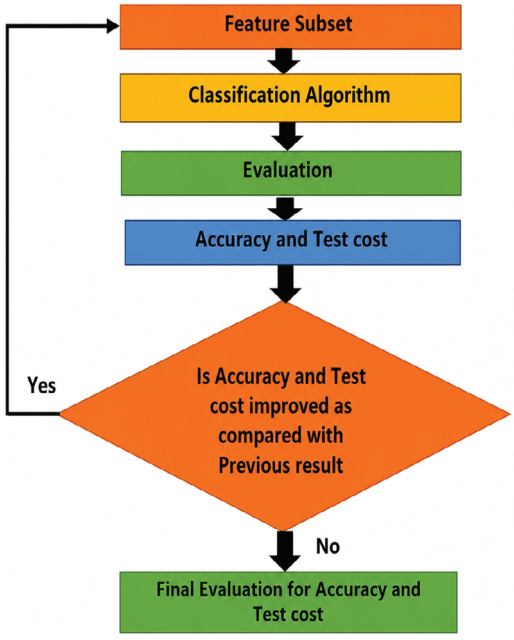

Fig 3. *Wrapper Framework for SCFS*

Putting the Framework to the Test

To evaluate the effectiveness of the proposed framework, experiments were conducted using multiple benchmark datasets obtained from the UCI Machine Learning Repository. These datasets vary in terms of feature dimensions, class distributions, and application domains, providing a rigorous environment for assessing the robustness of the proposed approach.

Training and testing datasets were generated using a 70:30 split, and preprocessing steps such as discretization were applied where required to support clustering and mutual information analysis.

How Swarm Intelligence Improved Feature Selection?

Experimental results demonstrate the effectiveness of PSO-based feature selection in identifying compact and informative feature subsets. The framework consistently achieved high classification accuracy while reducing the number of selected features. The impact of PSO-based feature selection on average feature subset size, classification accuracy, and standard deviation across different datasets is presented in Figures 4(a), 4(b), and 4(c), respectively. A comparative performance analysis of LFS, GSBS, and PSOBE approaches is shown in Figure 5.

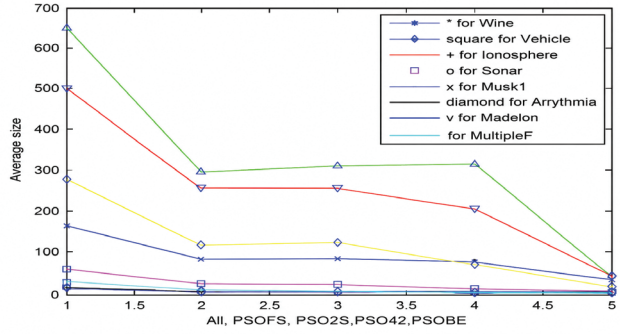

Fig 4(a): *Evaluation of PSO approach on different datasets for average size*

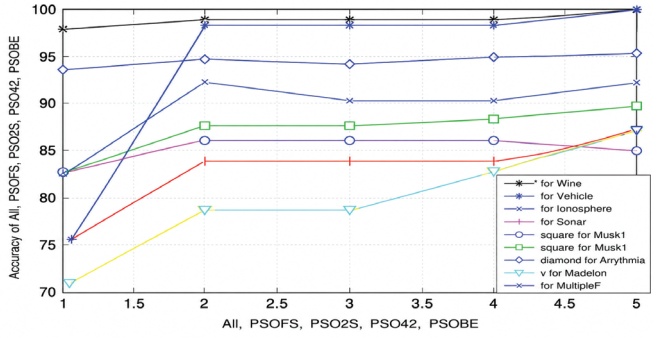

Fig 4(b): *Accuracy as per PSO approach*

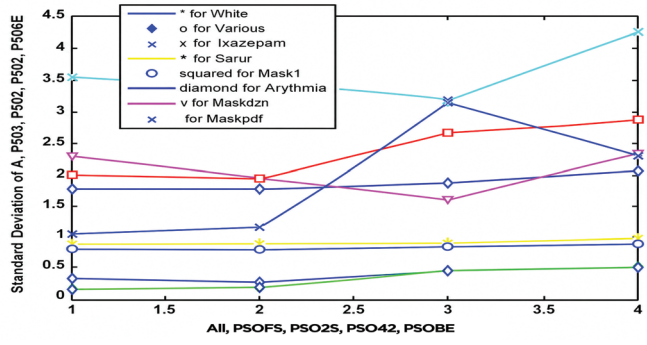

Fig 4(c): *Standard Deviation values as per PSO approach*

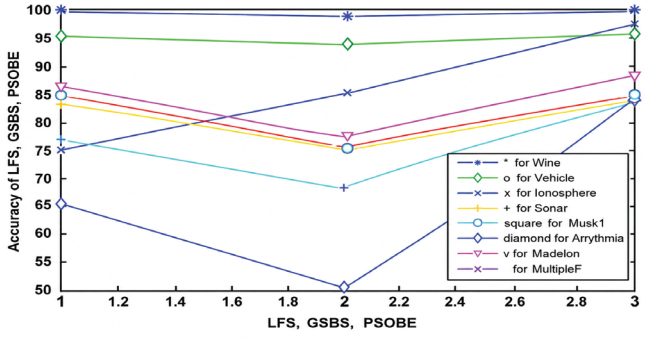

Fig 5: *Performance of LFS and GSBS*

The results indicate that PSOBE successfully balances feature reduction and predictive performance across multiple datasets. Compared with traditional PSO variants, the proposed approach selects significantly fewer features while maintaining comparable or superior classification accuracy.

Outperforming Conventional Methods

The performance of the proposed framework was further compared with established feature selection techniques such as Local Feature Selection (LFS) and Greedy Stepwise Backward Selection (GSBS). Across most datasets, PSOBE demonstrated superior performance by achieving higher classification accuracy using fewer features.

Additional experiments conducted on the Diabetes dataset further validated the effectiveness of the framework. The integration of Random Forest Classifier (RFC) and Recursive Feature Elimination (RFE) enabled the identification of highly informative features while maintaining excellent predictive accuracy and reasonable computational time. A detailed comparison of computational performance, including CPU time, wall time, and classification accuracy under different feature-selection settings, is presented in Table 1.

Table 1: Computational time for Diabetes dataset

S.No.	Items	With RFC	Without RFC	With RFE	Without RFE
CPU Times	User times	364 ms	349 ms	338 ms	361 ms
	System times	28.3 ms	31.4 ms	35.5 ms	22.6 ms
	Total Times	393 ms	380 ms	374 ms	384 ms
	Wall Times	444 ms	449 ms	374 ms	384 ms
	Accuracy	0.995	0.995	0.99	0.995

Conclusion

This study demonstrates the effectiveness of integrating swarm intelligence, feature clustering, structured ranking, backward elimination, and cost-sensitive optimization within a unified feature selection framework. By simultaneously addressing classification accuracy, feature reduction, and computational cost, the proposed approach provides a practical and scalable solution for explainable machine learning across diverse datasets.

Experimental results confirm that the framework consistently identifies informative feature subsets while maintaining high predictive performance and reducing computational overhead. The proposed Structured Feature Ranking and PSOBE approaches further enhance the transparency and efficiency of data-driven decision-making processes.

As machine learning systems continue to expand into critical domains such as healthcare, social analytics, cybersecurity, and business intelligence, the demand for explainable and trustworthy artificial intelligence will continue to grow. The proposed framework represents an important step toward developing transparent, efficient, and scalable machine learning solutions capable of extracting meaningful insights from increasingly complex computational social systems.

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Dept. of IT

Motor-Operated Panchagavya Mixer: Advancing Organic Farming Through Mechanization

Dr. T. Prabhakara Rao, *et al.*

Organic farming relies heavily on high-quality bio-fertilizers such as Panchagavya, yet their preparation remains labor-intensive and time-consuming. To address this challenge, researchers developed a motor-operated Panchagavya mixer that combines engineering innovation with sustainable agriculture. The system ensures uniform mixing, reduces preparation time, minimizes labor requirements, and operates with very low energy consumption. By modernizing a traditional agricultural practice, this technology offers farmers an efficient, cost-effective, and scalable solution for producing organic inputs while supporting environmentally sustainable farming.

Transforming Traditional Bio-Fertilizer Preparation Through Smart Engineering

The growing global demand for sustainable and chemical-free agriculture has increased the importance of organic farming practices. Among the various organic inputs used by farmers, Panchagavya has gained considerable recognition for its ability to improve soil fertility, enhance microbial activity, stimulate plant growth, and increase crop productivity.

Panchagavya is a traditional fermented bio-formulation prepared from five cow-derived ingredients-milk, curd, ghee, urine, and dung. Rich in beneficial microorganisms, nutrients, and plant growth-promoting substances, it has been extensively used by organic farmers across India as a natural alternative to synthetic fertilizers.

Despite its proven agricultural benefits, the preparation of Panchagavya remains a labor-intensive process. Traditional preparation methods require repeated manual stirring several times a day throughout a fermentation period of nearly 15-20 days. Maintaining homogeneity becomes increasingly difficult as batch volumes increase, resulting in inconsistent product quality and limited scalability.

Recognizing these challenges, researchers from the Department of Agricultural Engineering, VFSTR, developed a Motor-Operated Panchagavya Mixer that combines engineering innovation with sustainable agricultural practices. The system was designed to improve mixing efficiency, reduce labor requirements, ensure product uniformity, and facilitate large-scale preparation of Panchagavya for modern organic farming applications.

Addressing a Critical Challenge in Organic Farming

The effectiveness of Panchagavya depends largely on maintaining a uniform distribution of nutrients and beneficial microorganisms throughout the fermentation process. Conventional manual stirring methods are physically demanding and often fail to provide consistent mixing, especially in larger batches.

Although simple hand-operated and crank-driven mixers have been introduced in some locations, most available systems lack scientific design considerations such as controlled agitation, energy efficiency, microbial preservation, and scalability. Consequently, farmers continue to face challenges in producing high-quality Panchagavya consistently.

To bridge this technological gap, the research team developed a dedicated motor-operated mixing system capable of delivering controlled low-speed agitation while preserving the biological integrity of the fermentation process.

Engineering a Practical Solution

The developed mixer consists of a 100-liter high-density polyethylene (HDPE) fermentation tank integrated with a low-speed electric motor, planetary gearbox, and specially designed helical ribbon mixing blade (Figure 1).

A 230 V single-phase motor was selected as the prime mover and coupled with a 10:1 planetary gearbox. This configuration reduces the operating speed to approximately 92 rpm while generating sufficient torque to mix highly viscous Panchagavya formulations effectively. The low-speed operation minimizes excessive shear forces that could negatively affect microbial populations responsible for fermentation.

The complete system was designed and optimized using Autodesk Fusion 360 software, allowing the researchers to evaluate structural integrity, mixing performance, and operational safety before fabrication.

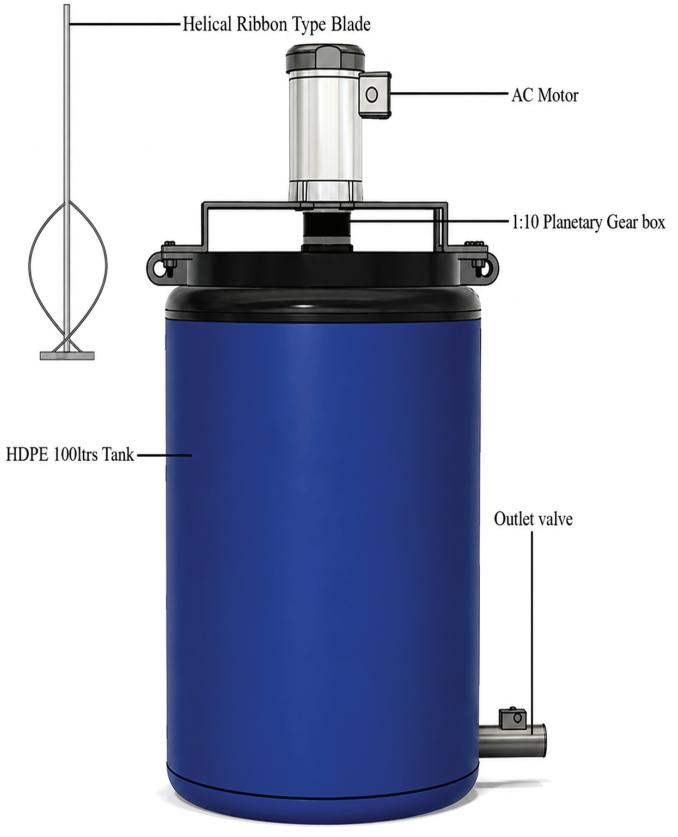

Fig 1. *Proposed CAD Model of the Motor-Operated Panchagavya Mixer*

Innovative Helical Ribbon Mixing Technology

One of the key innovations of the developed system is the use of a helical ribbon-type mixing blade fabricated from food-grade stainless steel (Figure 2). Unlike conventional propeller-based mixers, the helical ribbon design simultaneously generates axial and radial flow patterns within the fermentation vessel. This dual-flow mechanism promotes efficient circulation of both liquid and solid components while minimizing unmixed regions and dead zones.

The blade effectively keeps heavier particles such as cow dung solids suspended throughout the mixing cycle, ensuring uniform nutrient distribution and enhanced fermentation efficiency. Several physical forces contribute to the effectiveness of the mixing process, including shear forces, centrifugal forces, drag forces, and buoyancy effects. By carefully balancing these forces, the system achieves thorough mixing without damaging the beneficial microorganisms that are essential for Panchagavya production.



Fig 2. *Developed Motor-Operated Panchagavya Mixer*

Performance Evaluation and Operational Efficiency

The developed mixer was evaluated at different batch capacities ranging from 50 to 100 liters and compared with conventional manual and crank-operated mixing methods. The results demonstrated significant improvements in mixing performance. The motorized mixer achieved approximately 98% homogeneity, ensuring a highly uniform distribution of nutrients and microbial populations throughout the formulation. Mixing time was also substantially reduced. While manual stirring required between 15 and 25 minutes depending on batch size, the motor-operated system completed the same process within 5 to 10 minutes. This represents a reduction of more than 60% in mixing time compared with traditional practices. The comparative performance of the three mixing approaches is illustrated in Figure 3, which clearly highlights the superior efficiency of the motorized system.

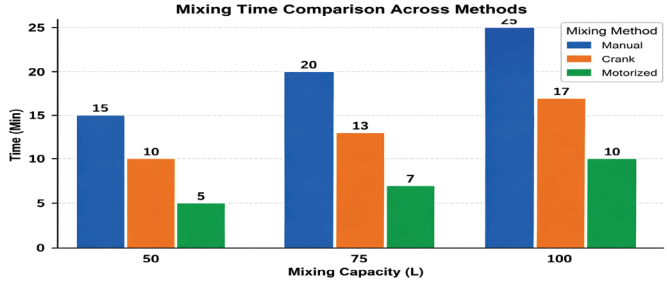

Fig 3. *Comparison of Mixing Time Among Different Mixing Methods*

Energy-Efficient and Cost-Effective Operation

Energy consumption is a critical factor influencing the adoption of agricultural mechanization technologies, particularly among small-scale farmers. The developed mixer demonstrated exceptional energy efficiency. Operating with a 0.186 kW motor, the system consumed only 0.0155–0.0310 kWh per batch depending on mixing volume. Even at maximum capacity, the electricity cost per mixing cycle remained negligible. The energy consumption profile at different batch capacities is presented in Figure 4.

The low energy requirement makes the technology economically attractive while simultaneously reducing environmental impact. Furthermore, the system can potentially be integrated with solar photovoltaic systems, enabling operation in remote agricultural regions with limited access to grid electricity.

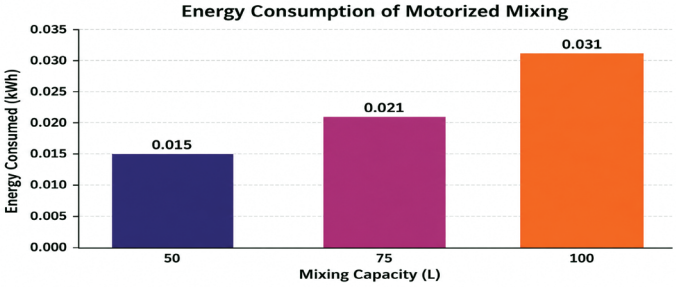

Fig 4. *Energy Consumption of the Motorized Panchagavya Mixer*

Reducing Labor Burden and Improving Farmer Productivity

One of the most significant advantages of the motor-operated mixer is the substantial reduction in labor requirements. Traditional Panchagavya preparation demands continuous physical effort, often requiring farmers to manually stir the mixture multiple times each day throughout the fermentation period. This repetitive activity can be physically exhausting and time-consuming. The motorized system reduces operator involvement to simple loading and switching operations. Active labor requirements are reduced to less than two minutes per mixing cycle, allowing farmers to dedicate more time to other essential agricultural activities. Based on typical rural labor costs, farmers preparing Panchagavya regularly could achieve considerable monthly savings while simultaneously improving product quality and consistency.

Mechanical Reliability and Operational Stability

Long-duration operational testing confirmed the reliability of the developed system. Motor temperatures remained below 45°C even after repeated mixing cycles, indicating effective heat dissipation and stable operation. Vibration analysis revealed minimal structural resonance, confirming the robustness of the HDPE tank and steel support frame. These findings demonstrate that the mixer can withstand prolonged use under routine agricultural conditions while maintaining consistent performance.

Supporting Sustainable and Organic Agriculture

Beyond its engineering achievements, the motor-operated Panchagavya mixer contributes directly to the advancement of sustainable agriculture. By enabling efficient production of high-quality organic bio-fertilizers, the technology reduces dependence on synthetic chemical fertilizers and promotes environmentally friendly farming practices. Improved nutrient cycling, enhanced microbial activity, and better soil health contribute to long-term agricultural sustainability. The technology also supports broader goals associated with resource-efficient farming, climate resilience, and sustainable food production systems.

Future Scope and Emerging Opportunities

The developed mixer provides a foundation for future innovations in organic input production.

Potential future developments include:

- Solar-powered operation for off-grid farming communities.
- IoT-based monitoring of fermentation parameters such as temperature and pH.
- Automated control systems for precision fermentation management.
- Larger-capacity units for farmer cooperatives and commercial organic-input manufacturers.

In addition to Panchagavya preparation, the same engineering principles can be applied to the production of vermiwash, fish amino acid formulations, microbial inoculants, and other liquid bio-fertilizers, expanding the impact of the technology across multiple agricultural sectors.

Conclusion

The Motor-Operated Panchagavya Mixer developed at VFSTR represents a successful integration of engineering innovation and sustainable agricultural practices. Through the incorporation of a low-speed, high-torque drive system and an optimized helical ribbon mixing mechanism, the technology delivers superior mixing homogeneity, reduced processing time, minimal energy consumption, and substantial labor savings. The innovation demonstrates how appropriate mechanization can modernize traditional agricultural practices while preserving their biological effectiveness. As organic farming continues to gain importance worldwide, technologies such as the motor-operated Panchagavya mixer offer practical and scalable solutions for enhancing productivity, sustainability, and farmer profitability.



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Towards Circularly Polarized Long Persistent and Photostimulated Luminescence in Organic Materials

Dr. Yemineni S. L. V. Narayana, *et al.*

Light can do much more than illuminate-it can also store, transmit, and protect information. This research introduces a new class of organic materials capable of producing long-lasting circularly polarized afterglow and photostimulated luminescence, enabling light emission that can persist for hours and be reactivated on demand. By combining chiral molecular design with advanced energy-transfer mechanisms, the study overcomes longstanding limitations of conventional luminescent systems. These breakthrough materials hold immense promise for secure optical encryption, anti-counterfeiting technologies, advanced displays, and next-generation photonic devices.

Illuminating the Future with Circularly Polarized Afterglow Materials

Circularly polarized luminescence (CPL) has emerged as one of the most fascinating optical phenomena in modern materials science, offering exciting opportunities for advanced applications such as three-dimensional displays, encrypted optical storage, anti-counterfeiting technologies, bioimaging, and secure photonic devices. Unlike conventional luminescent materials, CPL-active systems emit light with a specific handedness - either right-handed or left-handed polarization - providing an additional level of optical information that can be exploited in next-generation optoelectronic and photonic technologies.

Despite significant advances in the development of CPL materials, extending their emission lifetime beyond a few seconds has remained a formidable scientific challenge. In most organic systems, excited states are rapidly deactivated through non-radiative decay pathways, resulting in short-lived luminescence. Overcoming this limitation requires innovative approaches capable of simultaneously maintaining circular polarization and long-duration light emission.

Addressing this challenge, the present research introduces a novel strategy that combines circular polarization with long-persistent luminescence (LPL) and photostimulated luminescence (PSL) in purely organic materials. Through the intelligent integration of chiral emitters, long-lived charge-separated states, Förster Resonance Energy Transfer (FRET), and upconversion mechanisms, the study provides the first demonstration of circularly polarized long-persistent luminescence (CP-LPL) and circularly polarized photostimulated luminescence (CP-PSL) in organic systems. This achievement represents a significant milestone in the development of advanced chiroptical materials.

Overcoming the Limitations of Conventional Luminescent Systems

The growing demand for sophisticated photonic technologies has created a need for materials capable of storing optical information for extended periods, emitting highly controlled polarized light, enabling secure optical encryption, supporting rewritable and photostimulated optical systems, and operating efficiently in flexible organic devices. However, conventional room-temperature phosphorescence (RTP) and thermally activated delayed fluorescence (TADF) systems generally exhibit emission lifetimes that extend only to the order of seconds, limiting their practical utility in long-term information storage and advanced photonic applications.

Achieving persistent luminescence while simultaneously preserving circular polarization remains particularly challenging. To overcome this barrier, the researchers developed a unique design strategy based on the integration of long-lived charge-separated states, Förster Resonance Energy Transfer, upconversion processes, and chiral organic emitters. The result is a new class of purely organic materials capable of generating long-duration circularly polarized afterglow emission, opening exciting possibilities for secure photonic technologies and advanced optical systems.

Designing a Chiral Platform for Persistent Luminescence

The foundation of this study lies in the careful selection of molecular components capable of supporting both persistent luminescence and circular polarization. The researchers employed the chiral emitter R/S-OBN-Cz in combination with the charge-separation matrix materials m-MTDATA, PPT, and mCBP. These materials were selected based on their favorable HOMO-LUMO energy

alignment, photophysical characteristics, and ability to generate stable charge-separated states essential for long-lived luminescence.

The chiral emitter exhibited several desirable characteristics, including strong circular dichroism (CD), mirror-image circularly polarized luminescence signals, high photoluminescence quantum efficiency, and excellent compatibility with organic persistent luminescence systems. These properties made the material an ideal candidate for constructing advanced chiral afterglow platforms capable of sustaining circularly polarized emission over extended periods.

Engineering Long-Lived Circularly Polarized Emission

To realize circularly polarized long-persistent luminescence, the researchers developed two complementary design strategies that exploit distinct energy-transfer pathways. These approaches combine charge storage, controlled energy transfer, and chiral emission to achieve long-duration circularly polarized afterglow in purely organic systems.

The overall molecular design and the mechanism responsible for circularly polarized long-persistent luminescence in the three-component system are illustrated in Figure 1. The figure highlights the molecular structures of the donor, acceptor, and chiral emitter, as well as the sequence of charge separation, energy transfer, and circularly polarized emission processes that underpin the observed afterglow behavior.

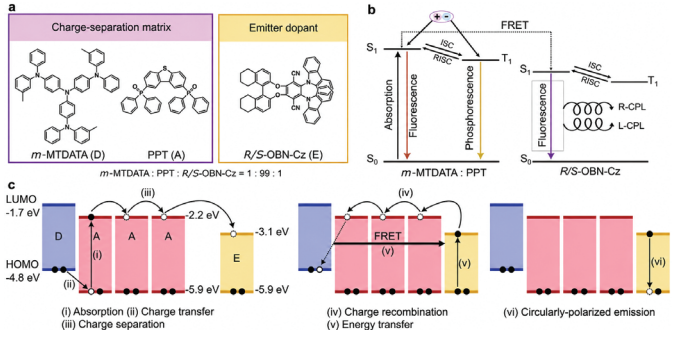

Fig 1. *Molecular structures and CP-LPL mechanism of the three-component FRET system*

Three-Component FRET System: Sustaining Circularly Polarized Afterglow

The first strategy employs a sophisticated three-component Förster Resonance Energy Transfer system. In this design, m-MTDATA and PPT function as a donor–acceptor pair capable of generating long-lived charge-separated states following photoexcitation. These charge-separated states act as temporary energy reservoirs, allowing excitation energy to be stored for extended periods before being gradually released.

As the stored charges recombine, the released energy is efficiently transferred to the chiral emitter R/S-OBN-Cz through the FRET process. Acting as the final emissive center, the chiral molecule converts this energy into circularly polarized long-persistent luminescence. Since the ultimate emission originates from the chiral emitter itself, the emitted light retains its characteristic handedness throughout the afterglow process.

The performance of the three-component system, including its emission decay behavior and circularly polarized luminescence characteristics, is presented in Figure 2. The results demonstrate efficient energy transfer from the charge-separation matrix to the chiral emitter, stable persistent luminescence, and retention of circular polarization during the afterglow period.

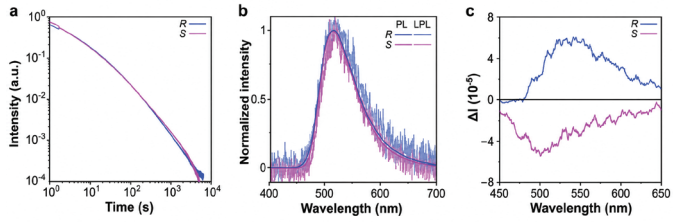

Fig 2. *Emission decay profiles and CPL characteristics*

A major advantage of this approach is its ability to simultaneously achieve prolonged emission duration, efficient energy transfer, stable persistent luminescence, and preservation of circular polarization. These characteristics make the system highly attractive for advanced photonic technologies requiring long-term optical information retention.

Two-Component Upconversion System: Simplifying Delayed Circularly Polarized Emission

To further simplify device architecture while maintaining efficient delayed emission, the researchers developed a two-component upconversion-based strategy. In this system, the excited charge-transfer state is converted back into the locally excited state of the chiral emitter, enabling delayed circularly polarized emission through energy upconversion. The effectiveness of this approach relies on the careful alignment of the HOMO energy levels of the donor material and the chiral emitter. This

alignment facilitates efficient charge recombination and restoration of the emissive excited state, allowing delayed luminescence to occur without relying on weak intermolecular charge-transfer emission pathways. As a result, the system combines architectural simplicity with highly efficient regeneration of locally excited states and excellent photoluminescence performance.

The design principle and operating mechanism of the upconversion-based CP-LPL system are illustrated in Figure 3. The figure highlights the energy-level alignment, charge-recombination pathway, and regeneration of the emissive state responsible for delayed circularly polarized luminescence.

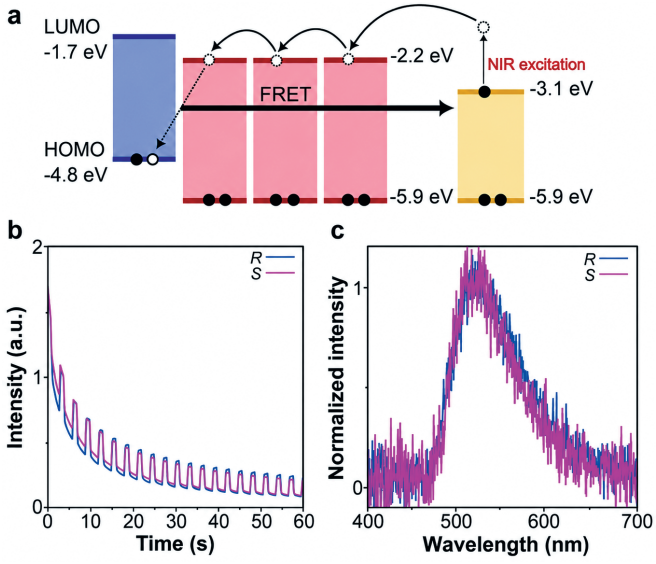

Fig 3. *Upconversion-based CP-LPL system*

Understanding the Mechanism of Circularly Polarized Long-Persistent Luminescence

The remarkable afterglow properties observed in the developed materials arise from carefully engineered energy-storage and energy-transfer processes. In the three-component FRET system, ultraviolet excitation generates long-lived charge-separated states within the donor–acceptor matrix. These stored charges gradually recombine over time, producing delayed energy transfer to the chiral emitter. Because the final emissive species is the chiral molecule R/S-OBN-Cz, the emitted light preserves its circular polarization throughout the luminescence process.

In contrast, the two-component upconversion system operates through efficient regeneration of the locally excited state of the chiral emitter. The close alignment of HOMO energy levels between the donor and chiral molecule facilitates charge recombination, excited-state restoration, and circularly polarized delayed emission. Importantly, this process occurs without dependence on weak intermolecular charge-transfer emission, thereby improving luminescence efficiency and system stability.

Reactivating Light on Demand: Circularly Polarized Photostimulated Luminescence

One of the most exciting achievements of this study is the successful demonstration of Circularly Polarized Photostimulated Luminescence. Unlike conventional luminescent systems that emit light immediately after excitation, CP-PSL enables optical information to be stored and subsequently retrieved on demand.

The process begins with ultraviolet irradiation, which generates and stores charges within the material. These trapped charges remain stable for extended periods, effectively functioning as an optical memory reservoir. Upon exposure to near-infrared (NIR) light, the trapped charges are released and the stored energy is converted back into luminescence. Remarkably, the regenerated emission retains its circular polarization, demonstrating the ability of the material to preserve chiral optical information even after prolonged storage.

The operating principle of CP-PSL, including NIR-triggered charge release and regeneration of circularly polarized emission, is illustrated in Figure 4.

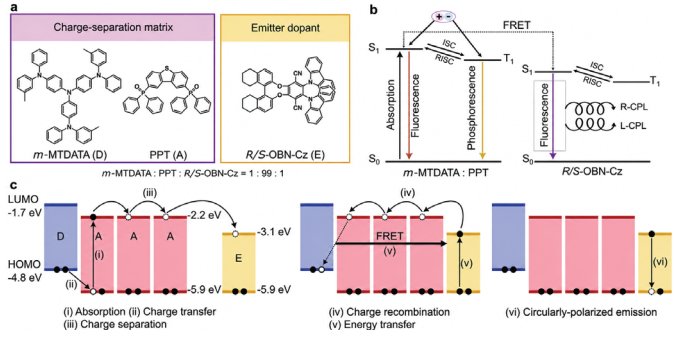

Fig 4. *Schematic illustration of circularly polarized photostimulated luminescence, including near-infrared stimulated charge release and regenerated circularly polarized emission.*

This unique capability enables a range of advanced functionalities, including optical memory storage, rewritable photonic systems, on-demand luminescence activation, and highly secure optical encryption technologies. The successful realization of CP-PSL therefore represents a significant breakthrough in the field of chiroptical materials and persistent luminescence research.

Performance Highlights of the Developed Systems

Experimental investigations demonstrated exceptional performance for both CP-LPL platforms. The three-component FRET system exhibited persistent luminescence extending beyond two hours, efficient charge trapping and release, stable mirror-image CPL signals, and highly effective energy transfer from the charge-separation matrix to the chiral emitter.

The two-component upconversion system displayed persistent luminescence durations approaching 100 seconds together with a remarkably high photoluminescence quantum efficiency of approximately 88%. The system also demonstrated efficient upconversion from the charge-transfer state to the locally excited state and strong delayed-emission characteristics.

The CP-PSL platform further confirmed the ability of near-infrared stimulation to regenerate luminescence while maintaining circular polarization. The observed reversible optical behavior highlights the robustness and practical potential of the developed materials for advanced photonic applications.

Confirming the Chiral Nature of the Emission

The films containing the R- and S-enantiomers exhibited clear mirror-image circularly polarized luminescence signals, opposite CPL profiles, stable optical chirality, and excellent experimental reproducibility. These observations provide compelling evidence that purely organic materials can successfully generate long-persistent circularly polarized luminescence while preserving their chiral optical characteristics over extended periods.

Scientific Significance and Future Opportunities

This work establishes a completely new proof-of-concept platform for chiroptical persistent luminescence, organic afterglow materials, circularly polarized optical memory systems, and photostimulated chiral emission technologies. By successfully integrating concepts from organic electronics, photophysics, chiral chemistry, optical engineering, and persistent luminescence science, the study creates an important bridge between multiple research disciplines.

The practical implications of these findings are equally significant. Circularly polarized afterglow materials could enable highly secure optical encryption systems, advanced anti-counterfeiting technologies, next-generation three-dimensional displays, optical memory devices with on-demand information retrieval, and highly sensitive bioimaging and sensing platforms. The ability to combine long-lived emission with controllable circular polarization offers exciting opportunities for future photonic and optoelectronic technologies.

A New Chapter in Chiral Organic Afterglow Materials

This study successfully demonstrates both circularly polarized long-persistent luminescence and circularly polarized photostimulated luminescence in purely organic systems. By integrating Förster Resonance Energy Transfer, upconversion strategies, long-lived charge-separated states, and chiral organic emitters, the researchers have created a new generation of photonic materials capable of persistent and re-stimulable circularly polarized emission.

The work opens exciting opportunities for future developments in secure photonics, optical storage, anti-counterfeiting technologies, and advanced organic optoelectronic devices. More importantly, it establishes an important milestone in the evolution of chiroptical organic materials and persistent luminescence technologies, paving the way for innovative applications that were previously difficult to achieve using conventional luminescent systems.

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Intelligent-based AT-SHAPF control for enhanced power quality in SOFC-driven Hybrid system

Dr. Balakrishna Kethineni, *et al.*

As modern power systems increasingly integrate renewable energy sources and fuel-cell technologies, maintaining power quality under dynamic operating conditions has become a critical challenge. This research presents an intelligent control strategy that combines artificial intelligence with advanced power filtering techniques to enhance the performance of SOFC-based hybrid energy systems. By employing an ANFIS-driven adaptive controller, the system effectively minimizes harmonic distortions, improves power factor, and ensures stable operation under varying load conditions. The study highlights the potential of AI-enabled energy management solutions for building smarter, more reliable, and energy-efficient power networks of the future.

Powering the future with intelligent energy systems

Amid rapid economic growth and modernization, energy demand continues to rise due to increasing population and improved living standards. Renewable energy sources offer a sustainable solution by providing clean energy, reducing carbon emissions, conserving natural resources, and delivering long-term economic benefits. Among these, fuel cells, particularly Solid Oxide Fuel Cells (SOFCs), have emerged as promising alternatives for enhancing distributed generation efficiency and addressing limitations of conventional renewable sources. This study comprehensively evaluates the performance of a proposed hybrid system under nonlinear load conditions, source-side disturbances, and sudden load variations. However, previous studies have shown that SOFC performance can significantly deteriorate during load transients due to its limited ability to respond quickly to abrupt changes in power demand.

Why power quality matters in hybrid energy networks?

While advancements in control strategies have enhanced the operational stability of standalone SOFCs, there is still a significant need for research addressing the evaluation of their integrated performance within unbalanced grid environments, particularly in terms of maintaining power quality and ensuring robust interaction under varying load conditions. Present studies have primarily focused on system performance using Conventional control techniques under steady-state and dynamic conditions for balanced grid-connected and islanded systems. However, existing approaches inadequately address the unpredictable uncertainties encountered in real-time operation, such as sudden phase imbalances and abrupt changes in nonlinear loads, thereby necessitating the adoption of more intelligent and adaptive strategies for effective power quality management.

Research Goals and Technological Vision

- To analyze the impact of nonlinear loads on power quality and SOFC performance in a DG-Grid hybrid system.
- Design and implement an Adaptive Tunable Shunt Active Power Filter (AT-SHAPF) for harmonic mitigation and power quality improvement.
- Implement and compare PI, FLC, and ANFIS controllers under dynamic and nonlinear operating conditions.
- Evaluate system performance using %THD, power factor, RMS error, and settling time.
- Improve SOFC stability, reliability, and lifespan under load variations and source disturbances.

Designing a Smarter Compensation Strategy

A modified instantaneous reactive power theory (IRPT) is employed to derive expressions for instantaneous real power and fictitious power from the Clarke transformed instantaneous voltages and currents, as follows.

Accordingly, the IRPT-based compensation method is systematically derived and presented as a step-by-step procedure.

- **Clarke Transformation:** Convert the three-phase instantaneous voltages and current into αβ reference frame.
- Compute Instantaneous power:Derive real *p* and imaginary *q* power.
- **Determine Reference compensation currents:** Isolate fundemental and Harmonic component.
- **Generate Reference currents:** Using inverse power equations to compute $i_{com_\alpha\beta}$ to $i_{ca^*,\ cb^*,}\ i_{cc^*}$ using inverse clarke transformation.
- **Inject Compensation:** Feed reference currents to PWM controller for AT-SHAPF operation.

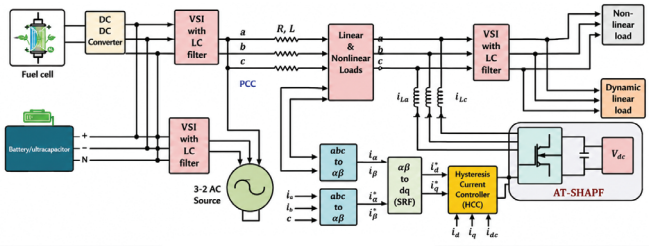

Fig 1 *SOFC integrated DG-Grid Hybrid System*

Modelling of Controllers

The Traditional Approach: PI Control

Figure.2 depicts the PWM control circuit for the AT–SHAPF, which is responsible for generating the current reference signals. The circuit encompasses active-power measurement, a PI controller, a low-pass filter, a reference-current generator, and hysteresis modules (i_a i_b i_c). It continuously monitors the point-of-common-coupling (PCC) voltages ($V_{\Phi a}$ $V_{\Phi b}$ $V_{\Phi b}$) and the DC-link voltage V_{DC} using these signals as feedback inputs. To regulate the SHAPF operation, compensatory reference currents are compared with the actual SHAPF currents ($I_{sh,a}$, $I_{sh,b}$, $I_{sh,c}$) inside a hysteresis band.

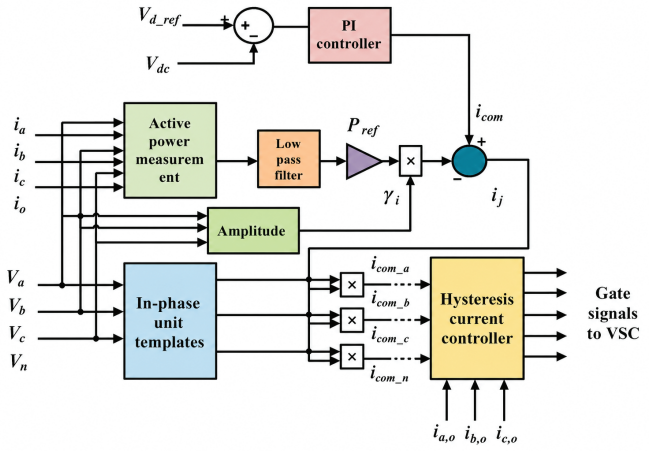

Fig 2 Creating gate control signals for AT-SHAPF.

Here, the PI controller was tuned using the Ziegler-Nichols method to regulate the system's output while ensuring stability and performance; the proportional gain K_p provides instantaneous error correction, and the integral gain K_i eliminates the steady state error.

Introducing Human-Like Decision Making

In this section, the fuzzy logic controller employs error and error rate as input variables. Each input undergoes fuzzification via seven membership functions, specifically: Positive small (PS), positive medium (PM), positive large (PL), negative large (NL), negative medium (NM), and negative small (NS). and Zero Error (ZE). which illustrate how the input values are mapped corresponds to different fuzzy sets represented in Figure. 3

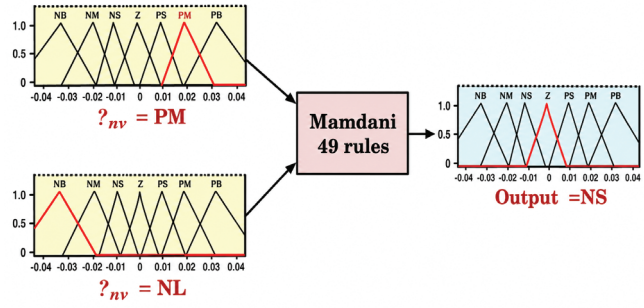

Fig 3 *Implementation of FLC*

The rule base for the proposed fuzzy logic system is structured such that each pair of input membership functions (input1_MF and input2_MF) determines an output membership function (weight), which reflects the activation strength of that rule.

When Artificial Intelligence Meets Power Electronics

This section introduces an ANFIS-driven Auto-Tuned Shunt Active Hybrid Power Filter (AT-SHAPF) to achieve dynamic adaptability and robust performance in the presence of unforeseen nonlinear load surges and source-side imbalance conditions.

The proposed architecture, illustrated in Figure. 4, represents an Adaptive Network-Based Fuzzy Inference System (ANFIS) configured with a single input (χ) and a single output (y), Intended to enable the implementation of the hybrid learning algorithm. following a Sugeno-type fuzzy system with 10 rules.

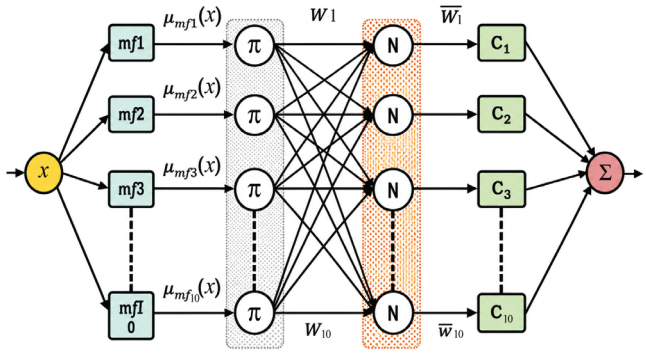

Fig 4 *ANFIS Framework for SISO System*

The membership function (mf) plots for the input variable "input1" in the ANFIS framework span an input range of 0–900 on the horizontal axis and a membership degree of 0–1 on the vertical axis. Ten overlapping triangular mfs ("in1 mf1" to "in1 mf10") divide the input space, each peaking at 1 and tapering linearly. This structure allows multiple mfs to be partially activated for instance, an input of 200 activates both "mf2" and "mf3"with each mf linked to a fuzzy rule that contributes to the weighted output shown in Figure .5

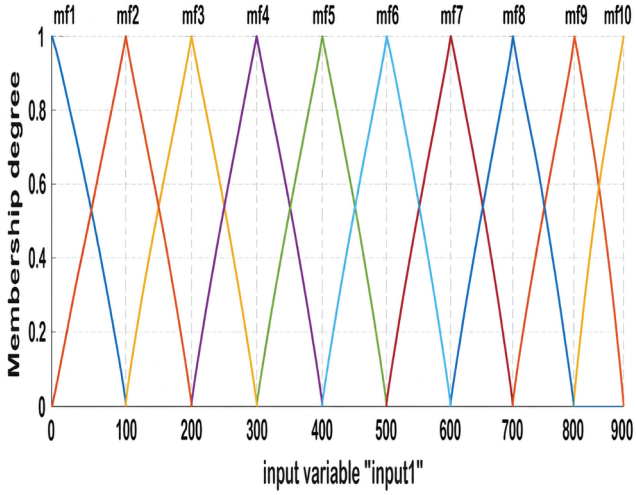

Fig 5 *Interpretation of ANFIS Input Membership Functions*

The proposed ANFIS model consists of 44 nodes, 10 fuzzy rules, and 40 trainable parameters. It achieved rapid convergence using hybrid optimization, reducing RMSE from 0.4673 to 0.0062 for training data and attaining 0.0071 for testing data. The model accurately captured complex system dynamics with strong generalization and minimal overfitting illustrated in figure.6 and figure.7

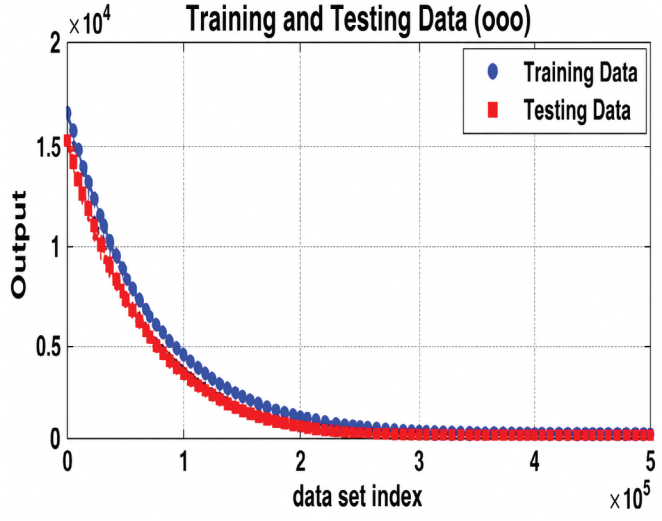

Fig 6 *Training and testing data curve*

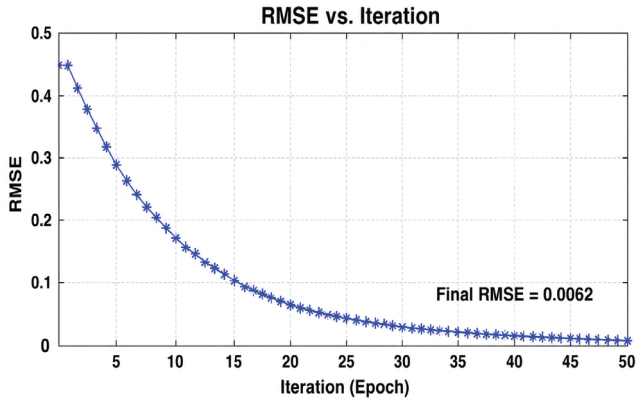

Fig 7 *Anfis training convergence curve.*

Transforming System Performance Through Intelligence

The SOFC-integrated DG-Grid hybrid system depicted in Figure 1 was examined under unbalanced source conditions while being subjected to nonlinear dynamic loads. Performance of the proposed ANFIS-based AT-SHAPF was evaluated through comparative analysis with conventional PI- and FLC-based AT-SHAPF controllers. To assess the effectiveness of the proposed ANFIS-based AT-SHAPF at the integrated point of common coupling (PCC), as well as the performance of partial pressures in the SOFC under dynamic nonlinear load conditions, multiple operational scenarios were simulated within the existing system, and the corresponding responses were systematically recorded.

The results demonstrate the effectiveness of the proposed AT-SHAPF in improving power quality under both steady-state and transient nonlinear load conditions with an imbalanced source. Without compensation, the system exhibited high harmonic distortion (%THD ≈ 29%) and poor power factor. The PI- and FLC-based controllers significantly reduced harmonics and improved the Current Distortion Factor (CDF) and true power factor. However, the ANFIS-based AT-SHAPF achieved the best performance, reducing %THD to 1.63% under steady-state conditions and 1.98% during transient load changes, while maintaining near-unity CDF (0.9995 and 0.9993) and true power factor (0.9984 and 0.9896). These results confirm the superior harmonic mitigation capability, adaptability, and power quality enhancement achieved by the ANFIS-based controller.

CONCLUSION

This study demonstrates the successful development of an intelligent power quality enhancement strategy for SOFC-integrated hybrid energy systems operating under

both steady-state and dynamically varying nonlinear load conditions. By combining an Adaptive Neuro-Fuzzy Inference System (ANFIS) with an Adaptive Tunable Shunt Active Power Filter (AT-SHAPF), the proposed approach effectively suppresses harmonic distortions, maintains stable system operation, and ensures superior power quality even under challenging operating environments.

Compared with conventional PI and Fuzzy Logic Controller (FLC) approaches, the ANFIS-based controller exhibited significantly improved performance, achieving lower Total Harmonic Distortion (THD), higher Current Distortion Factor (CDF), and near-unity power factor under both steady-state and transient load conditions. The intelligent learning capability of ANFIS enabled rapid error convergence, enhanced adaptability, and faster response to sudden system disturbances.

Beyond improving electrical performance, the proposed control strategy also contributed to more stable fuel cell operation by maintaining favorable hydrogen, oxygen, and water-vapor partial pressure dynamics within the SOFC. These improvements are essential for enhancing fuel cell efficiency, reliability, and long-term operational stability.

Thus, the findings highlight the potential of artificial intelligence-driven control systems to address complex power quality challenges in modern hybrid energy networks. The proposed ANFIS-based AT-SHAPF provides a promising pathway toward smarter, more reliable, and energy-efficient power systems capable of supporting the future integration of advanced fuel-cell and renewable-energy technologies.

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Dr. Balakrishna Kethineni
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