ISBN: 978-93-48620-02-6

Contemporary Developments in Science and Technology

Volume I

Editors:
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Bhumi Publishing, India

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First Edition: June 2025

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(ISBN: 978-93-48620-02-6)

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Published by:

Bhumi Publishing

BHUMI PUBLISHING

Nigave Khalasa, Tal – Karveer, Dist – Kolhapur, Maharashtra, INDIA 416 207

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PREFACE

The rapidly evolving landscape of science and technology continues to redefine the way we perceive, interact with, and improve the world around us. The present book, Contemporary Developments in Science and Technology, is a compilation of cutting-edge research, critical reviews, and innovative perspectives that reflect the dynamic progress occurring across various scientific and technological domains. It aims to serve as a valuable resource for academicians, researchers, industry professionals, and students who seek to understand the current trends and future directions shaping the modern scientific world.

This volume brings together multidisciplinary contributions that span fields such as physical sciences, life sciences, information technology, environmental science, biotechnology, materials science, and engineering. The chapters not only highlight theoretical advancements but also emphasize practical applications and the societal impacts of these emerging technologies. Special attention is given to sustainable innovation, digital transformation, and the ethical implications of scientific progress.

The book underscores the importance of an integrated approach in solving contemporary challenges—be it climate change, public health, food security, or energy efficiency—through the fusion of scientific knowledge and technological innovation. Each contribution has been carefully selected and peer-reviewed to ensure academic rigor, relevance, and clarity. The diversity of topics and authors reflects a collaborative spirit and a shared commitment to fostering knowledge dissemination and interdisciplinary dialogue.

We believe that Contemporary Developments in Science and Technology will inspire readers to explore new ideas, engage in meaningful research, and contribute actively to the advancement of their respective fields. As we navigate an era marked by both unprecedented innovation and complex global challenges, the role of science and technology in driving positive change is more crucial than ever.

We extend our sincere gratitude to all contributors, reviewers, and supporting institutions whose efforts have made this publication possible. It is our hope that this book becomes a useful guide and a catalyst for further exploration in the fascinating journey of scientific and technological progress.

- Editors

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COMPREHENSIVE REVIEW OF ADVANCES IN HOMOGENEOUS CATALYSIS: EMERGING MECHANISM, COMPUTATIONAL, STRUCTURAL, TECHNOLOGICAL FRONTIER, INNOVATION AND APPLICATIONS

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Abstract:

This review synthesizes recent progress in the field of homogeneous catalysis as presented in a series of research and review articles. It focuses on ligand design and self-assembly, computational chemistry, and the transition from homogeneous to heterogeneous catalytic systems. Additionally, it evaluates innovations in catalyst recovery, mechanistic understanding through spectroscopy, and the utilization of noble metals such as gold and platinum. This integrated analysis offers insights into emerging technologies and methodologies aimed at optimizing catalyst efficiency, sustainability, and industrial applicability. Homogeneous catalysis, involving catalysts and reactants in the same phase, plays a critical role in modern chemical synthesis. Transition metal complexes and advanced ligand architectures offer high selectivity and efficiency in a variety of transformations. This review highlights the mechanistic insights, ligand design strategies, computational modeling, electrochemical approaches, and sustainable practices associated with homogeneous catalysis. Drawing from recent literature, we explore the challenges and future directions in this dynamic field.

Keywords: Homogeneous Catalysis, Ligand Design, Computational Chemistry, Catalyst Recovery, Transition Metals, Sustainable Synthesis

1. Introduction:

Homogeneous catalysis is a core strategy in modern chemical synthesis, where the catalyst exists in the same phase—typically a liquid—as the reactants. Unlike heterogeneous systems, homogeneous catalysts offer molecular-level control, fine-tuning of reactivity, and exceptional selectivity. These properties make them invaluable in the development of green technologies, pharmaceuticals, and fine chemicals. Recent progress spans areas such as computational chemistry, low-temperature hydrocarbon oxidation, electrochemical applications, and main-group catalysis. Homogeneous catalysis is a pivotal strategy in chemical synthesis, particularly due to the precise control it allows over reaction pathways. Catalysts, usually transition metal complexes, are dissolved in the same phase as the reactants, enabling detailed mechanistic study and fine-tuning of activity and selectivity (Halpern, 2009). The widespread use of these systems in hydrogenation, oxidation, and C–C bond formation underscores their versatility and relevance in both academic and industrial chemistry. Homogeneous catalysis plays a central role in chemical synthesis, offering high activity, selectivity, and the ability to be finely tuned through ligand and metal complex design. However, challenges such as catalyst recovery, stability, and scalability persist. The documents reviewed here reflect the broad spectrum of strategies employed to overcome these limitations, ranging from molecular design and theoretical modeling to physical separation techniques and material science innovations. Homogeneous catalysis, where the catalyst and reactants reside in the same phase—typically a liquid—has transformed chemical synthesis. Unlike heterogeneous catalysts, homogeneous systems provide greater control over the reaction environment, enabling fine-tuning of reaction pathways and selectivity. This review synthesizes key insights from recent publications covering fundamental concepts, innovative methodologies, and real-world applications of homogeneous catalysis, particularly in the realms of green chemistry and sustainable energy.

2. Fundamentals of Homogeneous Catalysis:

The core of homogeneous catalysis lies in organometallic complexes that mediate chemical transformations via transition metal centers coordinated with ligands. Ligand architecture greatly influences catalytic activity through electronic effects and steric hindrance. Common transformations include hydrogenation, hydroformylation, oxidation, and C–C coupling. These systems are widely studied using computational tools that offer mechanistic insights into activation barriers, intermediate stability, and selectivity.

Hydrogenation remains one of the most studied applications of homogeneous catalysis (Bhaduri and Mukesh 2000). document classical systems using rhodium and ruthenium complexes. More recent work (as in the "Efficient Homogeneous Catalytic Hydrogen" paper) discusses proton-coupled electron transfer mechanisms and the role of water as a benign hydrogen source, aligned with green chemistry goals.

2.1. Electrochemical Homogeneous Catalysis:

Electrochemistry provides an alternative energy input for catalysis, allowing redox control without chemical oxidants or reductants. (Cheng *et al.* 2022) transition metal complexes operate in electrochemical environments, enabling efficient C–H activation and asymmetric synthesis. Challenges remain, including electrode stability and ligand degradation.

2.2. Spectroscopic Insights into Catalytic Mechanisms:

Goswami *et al.* (2015) demonstrate the value of EPR spectroscopy in understanding paramagnetic species in catalysis. This method complements traditional NMR by enabling the study of open-shell systems and transient intermediates. EPR has proven especially useful in identifying metal- and ligand-centered radicals and deciphering their roles in bond-forming reactions.

2.3. Microkinetic Modeling:

Traditional kinetic modeling often fails to capture the complexity of multistep catalytic cycles. Microkinetic modeling addresses this by integrating rate constants of elementary steps into a network, predicting concentration profiles over time. This modeling has gained traction due to increased computational power and accuracy of DFT calculations. It bridges theory with experiment, enabling the design of catalysts that maximize turnover frequency and minimize side reactions.

2.4. Heterogenization of Homogeneous Catalysts:

Witham *et al.* (2009) explore methods to transition homogeneous systems to heterogeneous forms. Witham *et al.* developed Pt nanoparticles with electrophilic character to replicate the behavior of homogeneous catalysts. Ye *et al.* used dendrimer-encapsulated metal clusters supported on mesoporous silica, maintaining high selectivity and reusability. These methods address challenges of catalyst recovery and enable use in flow reactors, bridging homogeneous performance with heterogeneous robustness.

3. CO_2 Reduction using Hydrosilanes:

The activation and conversion of CO_2, a stable greenhouse gas, represent a key challenge and opportunity in green chemistry. Hydrosilylation, catalyzed by transition metal complexes, is a promising pathway due to its favorable thermodynamics—primarily from the strong Si–O bond formation (Fernández-Alvarez *et al.* 2013). demonstrated that ruthenium, iridium, and other metals effectively catalyze the reduction of CO_2 to silyl formates and methoxysilanes, which are valuable intermediates in organic synthesis.

Wilson *et al.* (2012) compare CO_2 reduction on metal surfaces and homogeneous complexes using DFT. They highlight how surface properties and metal identity influence activation energy and selectivity. Their comparative approach offers valuable insights into the design of catalysts for environmental applications, particularly in carbon capture and utilization.

4. Metal Catalysis:

4.1. Gold(III) Catalysis:

Gold catalysis, once considered too expensive for widespread use, has seen a resurgence due to its unique reactivity. (Rocchigiani and Bochmann 2020) reviewed recent developments in Au(III) chemistry, showing gold's capability for redox-neutral transformations, migratory insertions, and selective C–H activations.

4.2. Noble Metal Catalysts: Gold and Platinum:

Schmidbaur and Schier (2012) provide a detailed review of Gold(III) complexes, highlighting their reactivity and catalytic potential in organic transformations. Despite their underutilization compared to Gold(I) analogs, Gold(III) catalysts offer promising selectivity and scope. A redox-mediated electrochemical method for recycling platinum group metal catalysts. This innovation significantly improves sustainability by enabling catalyst recovery with minimal energy input.

4.3. Ruthenium Amidinate Complexes:

Transition metal amidinates are potent catalysts for C–H and C–C bond activation. 16-electron Ru amidinates, demonstrating reactivity across multiple oxidation states. These findings underscore the structural flexibility and synthetic potential of ruthenium complexes in homogeneous systems (Nagashima *et al.* 2003).

5. Advances in Computational Catalysis:

Density functional theory (DFT) has revolutionized how we design and understand catalysts. A novel gradient approximation functional (GAM) that improved accuracy and transferability for transition metal complexes. The functional enabled efficient, low-cost simulation of catalytic processes, which is vital for screening large catalyst libraries (Yu *et al.* 2015).

5.1. Computational Bridges between Catalysis Domains:

For the unification of homogeneous and heterogeneous catalyst modeling via shared computational tools. Energetic span models, volcano plots, and energy decomposition analysis now inform rational catalyst design across diverse systems. These tools are pivotal for linking structure and performance. (Falivene *et al.* 2018)

5.2. AI Approaches to Homogeneous Catalysis with Transition Metal Complexes:

Exploration of the emerging role of artificial intelligence in catalysis research, particularly in the design and optimization of transition metal complexes. The paper reviews machine learning models and data-driven approaches that accelerate catalyst discovery, predicting performance and guiding synthetic strategies. This forward-looking review bridges computational and experimental catalysis, illustrating a paradigm shift in catalyst development (Morán-González *et al.* 2025).

5.3. Computational Modeling and In Silico Design:

Computational chemistry is increasingly important for designing homogeneous catalysts. As shown in the HAL manuscript and other sources, density functional theory (DFT) and molecular dynamics allow researchers to predict intermediate species, activation energies, and potential catalyst decomposition pathways. These methods bridge experimental gaps and guide synthetic efforts.

5.4. Computational Approaches in Homogeneous Catalysis:

Funes-Ardoiz and Schoenebeck provide a perspective on computational chemistry tools from DFT to machine learning. They emphasize how these tools enable mechanistic insight and rational catalyst design. Notably, DLPNO-CCSD(T) calculations have made it feasible to model entire catalytic cycles with high accuracy. The integration of data-driven models further enhances predictive capabilities, facilitating the exploration of vast chemical spaces.

5.5. Automated In Silico Catalyst Design:

Machine learning and high-throughput virtual screening are revolutionizing catalyst discovery. Tools automate the exploration of chemical space, optimizing molecular structures based on predicted properties. De novo design strategies, informed by statistical models and big data analytics, help navigate complex design landscapes. Automated workflows accelerate the transition from conceptual design to viable catalysts ready for synthesis and testing.

6.1 Integrated Biodiesel Production:

The article on integrated biodiesel production offers a comprehensive overview of current methodologies aimed at optimizing biodiesel synthesis, emphasizing the integration of processes for enhanced efficiency and sustainability. It discusses the challenges of feedstock variability and catalyst reuse, providing a critical evaluation of recent technological advancements and their industrial applicability. The review highlights both chemical and enzymatic catalytic pathways, showcasing the potential for integrated biorefineries to improve economic viability and environmental impact (Gemma Vicent *et al.* 2003).

6.2 Applications in Biomass Conversion:

Lignocellulosic biomass, triglycerides, and fatty acids are being valorized into fuels and chemicals using homogeneous systems. Well-defined catalysts achieve high selectivity in breaking complex polymers into monomers or converting alcohols to esters. The flexibility of homogeneous catalysts enables tailored strategies for each biomass type, optimizing conversion efficiency.

7. Mechanistic Principles and Ligand Design/ Catalyst:

Understanding the role of metal-ligand coordination is fundamental to designing effective homogeneous catalysts. Coordination compounds offer dynamic control over electron transfer, oxidation states, and substrate activation. Chelating ligands stabilize active species and can drastically influence turnover frequencies and catalyst lifetimes. (Halpern,2009)

7.1. Catalyst Design Strategies:

Dendrimer-based catalysts provide a hierarchical, branched architecture enabling multiple active sites and cooperative effects. Dendritic structures can encapsulate metal centers, leading to enhanced stability and activity. Ligands such as phosphines and carbenes modulate metal reactivity, while pincer complexes offer rigid frameworks ensuring high selectivity and durability.

7.2. Ligand Design and Functional Architectures:

Ligands are not merely spectators; they dictate the geometry, electronics, and reactivity of the metal center. The use of iminophosphorane-phosphine ligands demonstrates how combining electron-rich and sterically hindered environments can lead to catalysts with tunable properties. Bidentate ligands and hydrogen bonding as a secondary interaction (Kitanosono & Kobayashi, 2006) further contribute to catalytic specificity.

7.3. Ligand Design and Self-Assembly in Catalysis:

Seiche and Breit introduces a novel approach to ligand generation based on a self-assembly mechanism utilizing an A-T base-pair model. This method facilitates the formation of bidentate ligands through hydrogen bonding, simplifying library generation. Their 4x4 ligand matrix demonstrated high regioselectivity in rhodium-catalyzed hydroformylation reactions. This work underscores the potential of biomimetic strategies in catalyst design, providing a flexible platform for rapid screening.

7.4. Catalyst Design for Hydrocarbon Oxidation:

On low-temperature, selective oxidation of methane and light alkanes. Using single-site transition metal catalysts, they achieved mild CH activations—processes typically requiring high temperatures in industry. These findings point to greener, scalable technologies for fuel and feedstock generation. (Conley *et al.* 2006)

Hydrogenation of Carboxylic Acid Derivatives:

Hydrogenation reactions are pivotal in converting carboxylic acid derivatives into alcohols—key transformations in both industrial and fine chemical contexts. Homogeneous systems using bifunctional Ru, Ir, or Mn complexes exhibit high selectivity, especially under milder conditions (Pritchard *et al.* 2015).

Main Group Catalysis: Diazaphospholenes and Diazaarsolenes:

Main group elements are gaining traction as catalysts. Group 15 heterocycles—specifically diazaphospholenes and diazaarsolenes. These low-valent compounds offer unique redox properties and catalyze reductions and hydroborations efficiently, all while offering sustainable alternatives to heavy-metal catalysts (Ould and Melen, 2020).

8. **Challenges and Future Perspectives:**

Key challenges in homogeneous catalysis include catalyst deactivation, separation from products, and the cost of precious metals. Advances in ligand development, catalyst anchoring strategies, and flow chemistry may offer solutions. Future work must focus on integrating machine learning, combinatorial synthesis, and sustainable design principles. Despite significant progress, issues such as catalyst recovery, long-term stability, and scalability persist. Future work should focus on integrating automation, AI-based modeling, and sustainability metrics.

Despite advantages, homogeneous systems face obstacles like catalyst recovery, stability under harsh conditions, and separation from products. Emerging solutions include dendrimer supports, biphasic systems, and integration with flow reactors. Ligand design and computational screening further aid in creating more resilient catalytic systems. The integration of bioinspired motifs, machine learning, and flow chemistry will redefine the next generation of catalysts. Ongoing efforts aim to balance performance with sustainability by using earth-abundant metals and recyclable ligands. A deeper mechanistic understanding, driven by computational and experimental synergy, will continue to propel the field forward.

9. **Industrial and Green Chemistry Applications:**

Homogeneous catalysis is widely applied in fine chemical synthesis, pharmaceuticals, and petrochemical transformations. Green chemistry principles are becoming embedded in catalyst design, focusing on atom economy, recyclability, and the use of earth-abundant metals. The challenge remains to make these systems scalable and economically viable without sacrificing activity. Sustainability goals prioritize processes that reduce waste, energy usage, and reliance on non-renewable feedstocks. Homogeneous catalysts play a vital role in green chemistry by enabling atom-economical transformations and minimizing by-products. Applications include CO_2 hydrogenation to methanol, selective oxidation of biomass-derived substrates, and water splitting for hydrogen production. Homogeneous catalysis has revolutionized the production of fine chemicals, agrochemicals, and pharmaceuticals. Examples include asymmetric hydrogenation for chiral drug intermediates, Heck and Suzuki couplings for C–C bond formation, and carbonylation for acetic acid production. Industrial implementation demands robustness, ease of separation, and recyclability, pushing innovation in immobilization and reactor design.

10. **Nanomaterials for Catalytic Applications:**

10.1.Types of Nanomaterials:

- Nanoparticle: (Small, Single units. Ranging from 1 to 100 nm)
- Nanotubes: (Cylindrical structures ; like carbon nanotubes)
- Nanosheets: (Two dimensional materials ; like Graphene)
- Nanowires: (Thin ; wire like structures)
- Nanocomposites: (Nanomaterials made from Nanomaterials embedded in a matrix)

10.2.Properties of Nanomaterials:

- High surface area
- Quantum effect: (It can exhibit unique electronic, optical or magnetic Properties)
- Increased strength: (Enhanced mechanical properties compared to bulk materials)

- Chemical Reactivity: (Often more Reactive than bulk materials due to surface atoms)
- Low melting point: (low melting point due to high surface area)

10.3.Applications:

- Medicine: (Drug Delivery, imaging, cancer treatment)
- Electronics: (Smaller, faster components, sensors)
- Energy: (solar cells, batteries and fuel cells)
- Environment: (Water purification, Pollution control)

Discussion on the nanomaterials synthesis, characterization, and catalytic properties of nanoscale materials. It highlights how size, shape, and surface chemistry affect catalytic activity and selectivity, providing examples across various reactions. The review stresses the importance of designing nanomaterials with tailored functionalities for sustainable catalytic processes. This thesis or report investigates the use of nanoparticles as recyclable catalysts, focusing on their stability, reusability, and performance in heterogeneous catalysis. The research underlines the benefits of nanoscale catalysts in terms of high surface area and ease of recovery, contributing to green chemistry principles.

11. **Catalysis, Reaction Engineering, New Reactors and Methods for Investigation:**

Catalytic processes with a focus on reaction engineering principles, integrates catalytic performance with reactor design, discussing scale-up challenges and strategies for industrial application. The study supports the development of catalysts that meet both activity and process compatibility criteria (Alexia N. Kim, *et al.* 2020).

New reactors introduce innovative designs and methodologies for studying catalytic reactions under controlled conditions. It emphasizes microreactor technology, advanced spectroscopic techniques, and real-time monitoring to elucidate reaction mechanisms and kinetics. These advancements enable more efficient catalyst screening and process optimization (Claude de Bellefon *et al.,* 1998).

Conclusion:

Homogeneous catalysis is a vibrant, interdisciplinary field advancing toward cleaner, more efficient chemical production. With progress in computational modeling, main group element applications, and electrochemical strategies, the future promises even greater integration of sustainability and innovation. Addressing challenges like catalyst stability, selectivity under electrochemical conditions, and large-scale recovery will be critical for industrial adoption. Homogeneous catalysis continues to evolve, providing critical tools for chemical synthesis in both academia and industry. Innovations in ligand design, electrochemical integration, and computational modeling are driving the next generation of catalysts. Addressing environmental and economic challenges will be essential for the widespread adoption of these systems in sustainable chemistry. Collectively, these works illustrate a multifaceted evolution in homogeneous catalysis, driven by synthetic creativity, computational power, and materials engineering. Innovations in ligand architecture, mechanistic probing, and recovery methods are expanding the applicability and sustainability of homogeneous systems. Continued integration of these approaches is essential for advancing catalyst performance and meeting industrial and environmental demands. Homogeneous catalysis remains a cornerstone of chemical innovation. Continued collaboration between computational and experimental scientists will drive future advancements in this field.

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ADVANCEMENTS IN DIGITAL HEALTH: TRANSFORMING PHARMACY PRACTICE WITH TECHNOLOGY

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Abstract:

Digital health technologies are revolutionizing pharmacy practice by transforming how pharmacists deliver care, manage medications, and engage with patients. These innovations-ranging from mobile applications and telehealth platforms to artificial intelligence and electronic health records-enhance the accessibility, efficiency, and quality of pharmaceutical services. Tools like remote monitoring devices, AI-powered inventory systems, and telepharmacy services are helping pharmacists overcome geographic barriers, streamline operations, and focus more on patient-centered care. Mobile health applications empower individuals to manage chronic conditions, improve medication adherence, and participate actively in their health journey. At the same time, artificial intelligence is enabling data-driven decision-making by identifying at-risk patients, optimizing medication regimens, and predicting clinical outcomes. Telepharmacy extends care to underserved populations, while AI-enhanced chatbots and virtual assistants provide continuous support, reminders, and medication guidance, ensuring personalized and timely interventions. Furthermore, electronic health records and interoperable systems allow seamless sharing of patient data, enhancing collaboration between healthcare professionals and improving patient safety. Despite these advancements, challenges such as data privacy concerns, regulatory complexities, and disparities in digital literacy remain. Addressing these issues through infrastructure investment, community outreach, and targeted education-particularly for pharmacy students-is vital to ensure inclusive and equitable digital health adoption. As technology continues to evolve, it is critical for pharmacists to stay informed and adaptable, leveraging digital health tools to provide safer, more efficient, and patient-focused care.

Keywords: Digital Health, Pharmacy Practice, Telepharmacy, Artificial Intelligence, Mobile Health Applications, Medication Adherence, Electronic Health Records, Remote Monitoring, Digital Literacy, Patient-Centered Care, Telehealth, Healthcare Technology.

Introduction to Digital Health in Pharmacy:

Digital health technologies are transforming the landscape of pharmacy practice, marking a significant shift in how patient care and medication management are approached [1]. Digital health is not just about incorporating new gadgets or software; it represents a fundamental change in the way pharmacists interact with patients, manage prescriptions, and ensure medication adherence. This shift is fueled by the widespread adoption and accessibility of advanced digital tools and platforms that enhance accessibility, efficiency, and the overall quality of care provided in pharmacy settings. These technologies allow for more personalized and proactive interventions, ultimately, these advancements contribute to better health outcomes at both individual and community levels. Digital health tools are evolving at an unprecedented pace, promising to transform healthcare delivery and consumption in ways that were previously unimaginable [2]. From mobile applications that track medication adherence to telehealth platforms that enable remote consultations, these innovations are reshaping the landscape of pharmacy practice. The capability to track patients from a distance and deliver instant feedback, and tailor treatment plans based on individual needs is becoming increasingly feasible. This evolution is not only changing how care is delivered but also how patients engage with their own health management, fostering a more collaborative and patient-centered approach. Digital health innovations present new possibilities to improve access, streamline processes, and elevate the standard of care within pharmacy practice, addressing many of the challenges that have traditionally plagued the profession [1]. For individuals residing in remote or medically underserved regions, digital health can bridge geographical barriers and provide access to specialized pharmaceutical services that would otherwise be unavailable. The efficiency gains from automated prescription processing, inventory management, and data analysis enables pharmacists to dedicate more time to patient counseling and making informed clinical decisions. In addition, gathering and interpreting large volumes of patient data supports the development of tailored treatment strategies, which enhances care quality and leads to better patient outcomes.

Telepharmacy: Expanding Access to Pharmaceutical Care

Telepharmacy is overcoming distance-related challenges and increasing the reach of healthcare services to wider populations fundamentally transforming the traditional pharmacy model [1]. This approach utilizes digital communication technologies to provide pharmaceutical care to individuals in distant or underserved locations where physical pharmacies are not easily accessible. By leveraging video conferencing, secure messaging, and remote dispensing technologies, telepharmacy enables pharmacists to remotely supervise medication dispensing, counsel patients on proper medication use, and monitor for potential adverse effects. This approach is especially valuable for individuals in rural areas, long-term care homes, and correctional facilities, helping ensure consistent access to necessary pharmaceutical care regardless of their geographic location. Telepharmacy leverages digital technologies to extend pharmacy expertise beyond the confines of physical locations, enabling comprehensive remote patient care [3]. This involves using a range of tools and platforms to deliver pharmaceutical services, including medication therapy management, prescription refills, and adherence monitoring. Artificial intelligence (AI) and machine learning (ML) are playing an expanding role in telepharmacy by streamlining routine tasks, customizing treatment strategies, and boosting patient involvement. For instance, chatbots powered by AI can offer round-the-clock assistance, address medication-related inquiries and sending reminders for timely dosing. This technology-focused method increases the effectiveness of telepharmacy operations while ensuring patients receive accurate and prompt information, ultimately supporting improved health outcomes. Telepharmacy encompasses various digital tools and systems, including e-prescribing platforms, automated dispensing units, and clinical decision support tools, all working together to streamline pharmaceutical care [4]. E-prescribing systems allow physicians to electronically transmit prescriptions directly to the pharmacy, reducing the risk of errors associated with handwritten prescriptions and improving the speed and accuracy of the dispensing process. Automated dispensing units use robotics and computerized systems to ensure precise and timely dispensing of medications, reducing the risk of human error and enhancing the management of pharmaceutical inventory. Clinical decision support tools provide pharmacists with real-time access to patient information, drug databases, and clinical guidelines, enabling them to support well-informed decisions regarding medication therapy and detect possible drug interactions or contraindications.

Mobile Health Applications: Empowering Patients

Mobile health apps enable individuals to actively manage their health, leading to notable improvements in overall health outcomes, fostering a proactive approach to personal well-being [1]. These applications provide a wide range of functionalities, from tracking medication adherence and monitoring vital signs to providing personalized health education and connecting patients with healthcare providers. By putting health information and management tools directly into the hands of patients, mobile health applications support individuals in making informed health choices and engaging more actively in their care. This increased involvement promotes better management of chronic illnesses, greater compliance with treatment regimens, and, as a result, improved overall health outcomes. Mobile devices and wearable technology personalize treatment and promote widespread adoption of wireless technology in healthcare, transforming how patients interact with their health management [5]. Devices such as smartphones, smartwatches, and other wearables can monitor numerous health indicators, such as physical activity, sleep quality, heart rate, and blood sugar levels. This data can be seamlessly integrated into mobile health applications, providing patients and healthcare providers with a comprehensive view of their health status. Continuous monitoring and real-time data collection enable tailored treatment approaches, prompt medical responses, and proactive control of chronic health conditions. The widespread adoption of these technologies is also driving innovation in healthcare, contributing to the creation of innovative and more efficient methods for providing healthcare services. Digital health applications support disease self-management, wellness, and well-being, offering a wealth of resources and education to patients, aiming to be more actively involved in managing their own health [6]. These apps offer reliable, research-backed information on a range of health-related subjects, such as preventing illnesses, maintaining a balanced diet, staying physically active, and managing stress effectively. They also offer tools for tracking progress towards health goals, setting reminders for medication adherence, and connecting with support groups and healthcare professionals. By equipping individuals with the knowledge and resources necessary for effective health management, digital health applications empower them to make positive lifestyle changes, improve their overall well-being, and reduce their risk of developing chronic diseases.

Artificial Intelligence (AI) in Pharmacy: Optimizing Medication Therapy

Artificial intelligence algorithms process patient data to detect patterns, forecast clinical outcomes, and enhance medication management strategies, representing a significant advancement in personalized medicine [1]. By processing large datasets from electronic health records, clinical studies, and other healthcare sources, artificial intelligence systems can uncover patterns and correlations that may not be evident to human analysts. These insights enable the prediction of patients at risk for specific health conditions, support the selection of personalized treatment strategies, and assist in fine-tuning medication dosages to reduce adverse effects while enhancing therapeutic outcomes. This data-centric method in medication management holds promise for improving clinical results and lowering overall healthcare expenditures. AI enhances medication management, improves healthcare services, increases accessibility, and optimizes patient outcomes through innovative solutions that address many of the challenges facing modern pharmacy practice [7]. Artificial intelligence-based tools can handle routine operations like processing prescriptions, managing inventory, and dispensing medications, allowing pharmacists to dedicate more time to direct patient care. These technologies also enhance the precision and speed of medication reconciliation, helping to minimize the chances of errors and adverse drug reactions. Additionally, AI-integrated telehealth solutions enable remote patient consultations and continuous monitoring, thereby improving access to pharmaceutical services in remote or underserved regions. By utilizing AI to optimize workflow, boost accuracy, and expand reach, pharmacies can provide care that is more efficient, effective, and centered around patient needs. The adoption of artificial intelligence can simplify intricate tasks such as managing inventory, verifying prescriptions automatically, and analyzing potential drug interactions, thereby enhancing the overall efficiency and precision of pharmacy workflows [3]. Artificial intelligence-driven inventory systems can forecast medication demand, maintain optimal stock levels, and minimize wastage, ensuring that essential drugs are consistently available. Automated tools for prescription verification can detect mistakes, discrepancies, and possible interactions, alerting pharmacists to potential concerns. Additionally, AI can evaluate patient information to uncover contraindications and possible drug interactions, supporting pharmacists in making well-informed therapeutic decisions and reducing the likelihood of adverse drug events.

Digital Health and Medication Adherence

Digital health tools are essential in enhancing patient adherence to medications and supporting effective disease management, helping to tackle one of the major issues facing modern healthcare [5]. Failure to follow prescribed medication schedules is a common issue that can result in negative health outcomes, higher medical expenses, and a decline in overall quality of life. Digital health solutions—including mobile apps, wearable technology, and telemedicine services-offer various functionalities to assist patients in adhering to their treatment plans and managing chronic illnesses more efficiently. These technologies can send medication reminders, monitor adherence patterns, deliver tailored guidance and educational content, and facilitate virtual communication with healthcare professionals for ongoing support and supervision. Telehealth and remote patient monitoring are vital aspects of digital health that promote better medication adherence by offering patients a convenient and efficient means to remain in contact with their healthcare providers [8]. Devices used for remote monitoring can record important health indicators like blood pressure, heart rate, and glucose levels, and send this information to healthcare professionals for assessment. Through telehealth services, patients can engage in virtual consultations with pharmacists and other medical experts to discuss their medications, raise any questions, and receive tailored guidance to enhance adherence. This form of remote care is especially helpful for individuals who face challenges in visiting healthcare facilities or who favor the ease of accessing care from home. AI-enabled chatbots and virtual assistants facilitate round-the-clock patient support, ensuring timely interventions for improved adherence and disease management, thus enhancing the overall patient experience [3]. These virtual assistants can provide medication reminders, answer questions about medications, offer personalized support and encouragement, and connect patients with healthcare providers when needed. By providing continuous access to information and support, AI-enabled chatbots and virtual assistants can help patients stay engaged in their own care, improve their adherence to medication regimens, and better manage their chronic conditions. This constant availability can be especially useful for patients who have complex medication regimens or who struggle with adherence due to cognitive or physical limitations.

Electronic Health Records (EHRs): Enhancing Collaboration and Safety

The use of secure electronic health records and interoperable systems enhances communication among healthcare providers, allowing for better coordination of care and improved patient outcomes, ultimately changing how medical professionals share and access vital information [1]. Electronic health records (EHRs) serve as a unified source for storing comprehensive patient data, such as medical history, current medications, known allergies, laboratory findings, and diagnostic images. With interoperable systems in place, healthcare professionals can securely access and share this information across various platforms, even if they use different EHR systems. This efficient flow of information enhances collaboration among providers, lowers the chance of mistakes, and supports the delivery of high-quality, well-coordinated care. Pharmacists can access comprehensive patient information through EHRs, facilitating informed decision-making and enhanced patient safety, leading to more effective medication therapy management [1]. By having access to a complete and up-to-date medical record, pharmacists can make more informed decisions about medication therapy, identify potential drug interactions or contraindications, and ensure that patients receive the right medications at the right doses. EHRs also provide pharmacists with valuable information about patient adherence, allowing them to identify patients who are struggling with their medications and provide targeted interventions to improve adherence. This access to comprehensive patient information empowers pharmacists to play a more active role in patient care and improve medication safety. EHRs are integral to contemporary pharmacy practice, and their use should be developed in pharmacy curricula to prepare students for advanced practice experiences, ensuring that future pharmacists are well-equipped to utilize this technology effectively [9]. Pharmacy schools should incorporate EHR training into their curricula, providing students with hands-on experience using EHR systems and teaching them how to access and interpret patient data. Students should also be taught how to use EHRs to document their clinical interventions, communicate with other healthcare providers, and monitor patient outcomes. By developing these skills early in their education, pharmacy students will be well-prepared to use EHRs effectively in their future practice and contribute to improved patient care.

Addressing Challenges in Digital Health Adoption

Concerns about data security, complex regulatory frameworks, and unequal levels of digital literacy among patients present major obstacles to implementation to the widespread adoption of digital health in pharmacy, requiring careful consideration and proactive solutions [1]. Patients may be hesitant to share their health information through digital platforms if they are concerned about privacy breaches or the misuse of their data. Regulatory frameworks for digital health are still evolving, creating uncertainty and complexity for healthcare providers and technology developers. Disparities in digital literacy can limit access to digital health tools for certain populations, such as older adults, individuals with low incomes, and individuals residing in rural regions face unique barriers. Overcoming these issues is crucial to guarantee that the advantages of digital health are accessible to all patients, regardless of their location or personal circumstances. Ethical considerations and regulatory compliance are critical in implementing AI in healthcare to ensure patient privacy and data security, safeguarding patient rights and promoting responsible innovation [7],[10]. Artificial intelligence systems depend on extensive patient data to generate insights and predictions, which raises important concerns regarding data privacy and the potential misuse of confidential information. To safeguard patient records from unauthorized access, strong security protocols—such as encryption and controlled access-must be in place. Additionally, clear regulatory guidelines are needed to oversee the ethical and responsible application of AI in healthcare, ensuring transparency and informing patients about how their data is collected and utilized. Digital health initiatives must address issues of poor infrastructure, poverty, digital divides, and low digital/health literacy to ensure equitable access and prevent the exacerbation of existing health disparities [11]. In many low- and middle-income countries, limited access to internet connectivity, reliable electricity, and digital devices can hinder the adoption of digital health tools. Poverty can also be a barrier, as patients may not be able to afford the costs associated with accessing digital health services. Digital divides, such as differences in access to technology based on age, education, and geographic location, can further limit the reach of digital health initiatives. Low digital and health literacy can also prevent patients from effectively using digital health tools, even if they have access to them. Tackling these issues demands a comprehensive strategy involving improvements in infrastructure, educational initiatives, and community engagement to ensure equitable access to digital health benefits for all individuals.

Digital Skills and Education for Pharmacists

It is important to develop digital health guidelines that support the ongoing technological advancements and empower community pharmacists to deliver care efficiently, highlighting the importance of preparing pharmacists for the digital age [12]. As digital health technologies become more prevalent in pharmacy practice, it is essential to provide pharmacists with the training and resources they need to use these tools effectively and confidently. This includes developing recommendations for pharmacy schools, professional organizations, and technology developers to ensure that pharmacists are well-prepared to meet the challenges and opportunities of the digital age. These recommendations should address topics such as digital literacy, data privacy, ethical considerations, and the integration of digital health tools into pharmacy workflows. Educating pharmacy students in digital health is essential to equip future pharmacists with the skills needed to effectively adapt to the rapidly changing healthcare environment [13]. Pharmacy schools should incorporate digital health training into their curricula, providing students with hands-on experience using digital health tools and teaching them how to access and interpret patient data. Students should also be taught how to use digital health tools to communicate with patients, monitor medication adherence, and provide remote consultations. By developing these skills early in their education, pharmacy students will be well-prepared to use digital health technologies effectively in their future practice and contribute to improved patient care. Pharmacy programs should embrace digital transformation and identify knowledge and skill gaps in applying technologies to solve clinical problems, ensuring that pharmacists are equipped to address the challenges of modern healthcare [14]. This includes conducting needs assessments to determine the specific digital health skills that pharmacists need to succeed in their practice. Pharmacy programs should also collaborate with technology developers and healthcare providers to develop and implement innovative digital health solutions that address unmet needs in pharmacy practice. By embracing digital transformation and addressing knowledge and skill gaps, pharmacy programs can ensure that their graduates are well-prepared to meet the challenges and opportunities of the digital age.

Impact on Community Pharmacy Practice

Digital technologies such as electronic prescriptions and real-time prescription monitoring improve timely access to medicines and facilitate clinical decision-making, transforming the way community pharmacists practice and interact with patients [15]. Electronic prescriptions (e-prescriptions) allow physicians to electronically transmit prescriptions directly to the pharmacy, reducing the risk of errors associated with handwritten prescriptions and improving the speed and accuracy of the dispensing process. Real-time prescription monitoring programs (RTPMPs) provide pharmacists with access to patient prescription histories, allowing them to identify potential drug interactions, overutilization, and other red flags. These technologies enable community pharmacists to make more informed decisions about medication therapy and provide better care to their patients. Community pharmacists recognize the value of digital health tools in evolving models of pharmacy practice, embracing these innovations to enhance their services and improve patient outcomes [16]. They see the potential of digital health to improve medication adherence, enhance patient engagement, and expand access to pharmaceutical care. Community pharmacists are also increasingly using digital health tools to provide new services, such as medication therapy management, remote consultations, and chronic disease management programs. By embracing digital health, community pharmacists are positioning themselves as key players in the evolving healthcare landscape and improving the health of their communities. Digital innovations enhance outcomes, but concerns about privacy and usability significantly affect user acceptance, highlighting the importance of addressing these issues to ensure widespread adoption [17]. Patients may be hesitant to use digital health tools if they are concerned about the privacy of their health information or if they find the tools difficult to use. It is essential to address these concerns by implementing robust data security measures and designing user-friendly interfaces that are easy for all patients to navigate. By addressing privacy and usability concerns, healthcare providers can increase patient acceptance of digital health tools and ensure that these innovations benefit all members of the community.

Future Trends and Innovations in Digital Pharmacy

Emerging trends in digital health include the use of artificial intelligence, blockchain, and online platforms to reshape pharmacy services and education, promising significant advancements in the field [18]. Artificial intelligence (AI) is being used to automate tasks, personalize treatment plans, and improve medication adherence. Blockchain technology is being used to secure patient data and improve the transparency and efficiency of the supply chain. Online platforms are being used to provide remote consultations, deliver educational resources, and connect patients with healthcare providers. These emerging trends have the potential to transform pharmacy practice and improve patient outcomes.

The integration of AI, machine learning, and digital health technologies will further improve decision-making and patient outcomes, drive innovation and transforming the future of pharmacy practice [19]. AI and machine learning can analyze vast amounts of patient data to identify patterns and predict health outcomes, allowing pharmacists to make more informed decisions about medication therapy. Digital health technologies can provide patients with personalized support and education, helping them to manage their chronic conditions more effectively. By integrating these technologies, pharmacies can deliver more efficient, effective, and patient-centered care. Future policy interventions must facilitate innovation and training in the digital pharmacy sphere to enhance healthcare sector development, ensuring that the benefits of digital health are realized and that pharmacists are well-prepared for the future [20]. This includes providing funding for research and development of new digital health technologies, supporting the development of digital health training programs for pharmacists, and creating regulatory frameworks that promote innovation while protecting patient safety and privacy. By implementing these policy interventions, governments can foster a thriving digital pharmacy sector that contributes to improved healthcare outcomes and a stronger economy.

Conclusion:

The integration of digital health technologies into pharmacy practice represents a transformative shift in how pharmaceutical care is delivered and experienced. From telepharmacy and mobile health applications to artificial intelligence and electronic health records, these tools are reshaping the pharmacist's role and enabling more personalized, efficient, and accessible care. They not only improve clinical outcomes and patient engagement but also optimize operational workflows, reduce medication errors, and extend healthcare access to underserved populations. However, to fully realize the potential of these innovations, it is essential to address challenges such as data privacy, regulatory compliance, and disparities in digital literacy. Ongoing education, infrastructure development, and supportive policy frameworks will be critical to overcoming these barriers. As the healthcare landscape continues to evolve, pharmacists must embrace a forward-thinking mindset, adapt to emerging technologies, and champion the use of digital solutions to enhance patient care. Ultimately, the successful integration of digital health into pharmacy practice promises a more connected, collaborative, and patient-centric future in healthcare.

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A NEW TECHNIQUE FOR MOTION ESTIMATION FOR OPTIMAL RATE DISTORTION IN VIDEO COMPRESSION

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Abstract:

State of the art technologies like multiple reference frame (MRF), Variable Size Block Matching (VSBM) and quarter pixel accuracy are used in video coding standards and strive to reduce temporal and spatial redundancies. It is evident from the literature review that around 70 %-90% of total computational power is used in motion estimation. Thus, reduction in redundancy and computational complexity of motion estimation is one of dominating research area in the area of video coding. Quad tree based algorithms for variable size block matching (VSBM) is one of the most popular technique available to reduce computational complexity along with redundancy in motion estimation. In this investigation, an efficient quad tree algorithm which is based on edges homogeneity with Lagrange multiplier optimization algorithm is used in motion estimation for finding multiple paths with multiple constraints with user defined rate distortion requirements. This algorithm permits adaptive bit allocation between Displaced Frame Difference (DFD) and Motion Vector Field (DVF). The rate distortion optimization (RDO) allows for trade-off between distortion and rate and it is build based upon quad tree with active and inactive region using edges homogeneity present in the frame. The simulation results calculate K-MCSP with provided constraints with optimal rate and distortion. It is now depends upon user to select the appropriate path depending on their requirements and constraints.

Keywords: Motion Estimation, Video Coding Standards, Quadtree, A* Prune Algorithm, Lagrange Operator.

1. Introduction:

Joint Video Team (JVT) which is formed by combining two premier international standardization organizations, ISO/IEC and ITU-T proposed H.264 AVC and H.265 High Efficiency Video Coding (HEVC), which are the most popular video coding standards [1-3]. Some of major goals of these video codec are to improve compression performance and reduction of bit rate. These goals are achieved at motion estimation part of encoder in video codec with variable block size and multiple reference frame (MRF) by minimizing the numbers of blocks and prediction error using variable block size matching [4].Variable block size techniques brought a significant change in quality of the video and are therefore found implemented in advance video coding standards like H.264 and H.265 HEVC but is also the most time-consuming component at encoder end. A number of new algorithms have been proposed by researcher for reducing the computation complexity and adaptively selecting the block sizes [5]. Fig. 1 shows various classifications of research methods to solve RD problem.

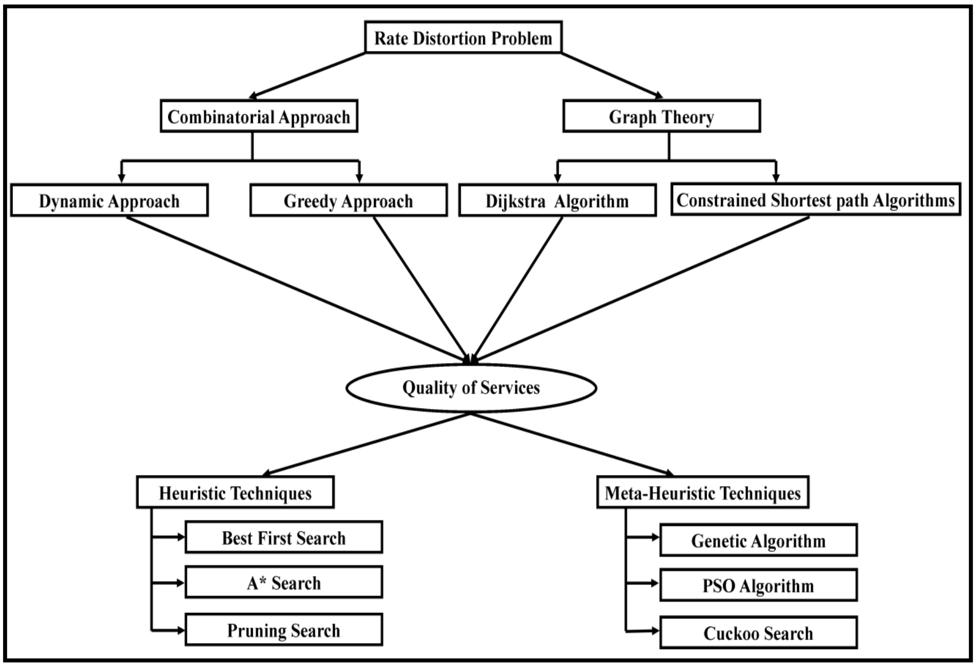

Fig. 1: Classification of research methods to solve R-D problem

In VBSM algorithms, complex motion can be described by smaller blocks while stationery content or uniform motion by larger blocks. However, selection of an appropriate block is one of the biggest problems and this gives rise to an interesting optimization problem without an efficient solution to this problem and is termed as NP hard. This practical problem can be tackled by using quad tree decomposition where each node has four children or none. At top of quad tree, block size is 16*16 and at bottom of 3rd level it is 4*4. The quad tree is pruned in active region and inactive region according to some threshold on edges present in frame to obtain blocks which are of variable sizes.

The rest of paper has been organized in the following order. Discussion on the quad tree technique and the method based on edge based algorithm which is used for video compression is presented in section II. Dijkshetra's algorithm considering multi constraint shortest path and rate distortion optimization is discussed in section III. The efficiency of the proposed edge-based quad tree algorithm in order to estimate the motion of the video compression without compromising on the big trade and computational complexity is highlighted in Section IV with the help of the experimental results. Section V concludes the findings of the study.

2. Content Based Quad Tree Algorithm for Video Compression

Fixed and Variable size block matching algorithms are used to find optimal rate distortion in video compression with different searching algorithms such as Dikshtra, A* search algorithm with pruning etc. There are numerous techniques to match variable block size in motion estimation; one of the vital techniques among them is quadtree which finds significant contribution in motion estimation [6]. In this method, each of the frames is first considered and divided into four number of blocks of size 16*16, after that each of the 16*16 blocks is considered and divided into four 8*8 blocks, which in turn is again sub divided into four 4*4 blocks. A decision criterion is applied to see if each variable size block should be encoded as single 16*16 block or further or four independent 4*4 blocks. A 2N*2N image block is decomposed into an $(N-n_o+1)$ level hierarchy of square blocks with the help QT structure. The blocks produced by this decomposition at level n has a size of 2n*2n, where, $0 \le n_o \le N$ as shown in fig. 2.

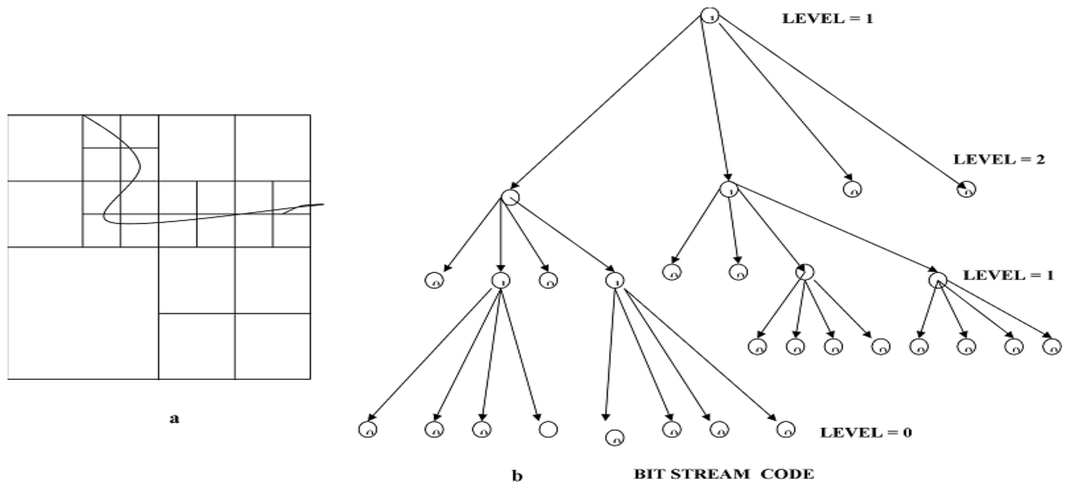

Fig. 2: Frame decomposition Using Quadtree and its presentation

Block based motion estimation algorithms are extensively used to exploit the temporal redundancies in video coding. But it is very difficult to estimate accurately the blocks located on boundaries of moving objects. As it is well known fact that human eyes are sensitive to edge details, therefore if edge detection techniques are including with motion estimation which improves the quality of the video.

The standard quad tree decomposition algorithms used in many image compression applications show poor rate distortion performance and creates blocking in the reconstructed image. These problems can be solved by improving rate distortion performance with optimal threshold adjustment on edges present in the active region of frame and assign optimal bits allocation for leaves coding. In this paper, we have presented an improved quadtree algorithm for motion estimation based on one of the important features, namely edge intensity present in given frame. Edge detection technique is used to produce an excellent image quality []. In this proposed Quad Tree decomposition, performance of 3*3 edge detector as used for homogeneity decision is investigated. The new quad tree decomposition algorithm with threshold on edges is as follows:

1. Find number of edges and edge intensity at each level using 3*3 edge detector based on active and inactive regions present in the frame. Enter the threshold value of edges for each block in current frame.
2. If number of edges in active region is greater than threshold value then split the parent node into 4 children nodes.
3. Otherwise, don't split region of interest and assign motion vector.
4. Repeat steps 2 & 3 for each 16*16, 8*8 and 4*4 micro-block present in current image.

Now to find optimal solution, coding bits are split into displaced frame difference (DFD) and displaced vector field (DVF) that closely resemble the size of micro-blocks. This problem escorts to rate distortion optimization in video compression. Lagrange multiplier is used to trade off between the bit rate and distortion. Lagrange multiplier optimization is gaining importance because of its effectiveness, conceptual simplicity and evaluate done in an optimized fashion []. Lagrange multiplier optimization technique is used for calculating optimal K- multiple constraints shortest paths.

3. Multi Constraints Shortest Paths in Video Compression

The block matching technique is the most popular tool in motion estimation and compensation, used for video compression techniques and Rate Distortion Optimization (RDO) problem is related to it. RDO problem is related to the family of NP hard problem which uses Lagrange's parameter to solve and find constrained path with some constraints which is to be achieved [9-12]. As bandwidth available for transmission is a dynamic parameter, whenever requirement changes, it MCSP (Multiple Constraints Shortest Path) procedure can be used effectively each time to find the best possible optimal solution with acceptable bit rate with reasonable loss in image quality. It is always time consuming to use all MCSP each time for finding best feasible solution. In order to find the best feasible solution in least possible time according to variation in dynamic parameters, K-MCSP (K-multiple constraints shortest path) method can be considered. Considerable reduction in time can be achieved as the selection of the best feasible path is done from multiple pre computed paths. A modified A* prune algorithms is used for MCSP which allows for controlling the contribution of different constraints simultaneously and also allows to choose from K paths which are produced due to variation in the dynamic parameters. In this work, A modified A* prune algorithm is used to solve Rate distortion Optimization (RDO) problem. Lagrangian bit allocation techniques is used for an efficient bit allocation between DFD (D) and DVF(R) given by Eq. 1 [13].

$$\mathbf{J} = \mathbf{D} + \boldsymbol{\lambda} * \mathbf{R} \qquad (1)$$

In Eq. 1, λ is Lagrangian Operator as dynamically changing constraints like bandwidth or quality of services, we proposed to use K-MCSP algorithm for finding one or multiple feasible paths subject to multiple constraints.

Considering a network with graph $G = (V, E)$ where V= set of nodes formed by quad tree and E= set of links in quad tree. Each link $(i, j) \in$ E is associated with R non negative and additive QoS: $w_r(i,j)$, r= 1,2,-,-, R. The cost function W_o defined as

$$\boldsymbol{W_o(i,j) = \sum_{r=1}^{R} a_r * w_r\,(i,j)} \qquad (2)$$

Now to find the first K-MCSP from source (s) to destination (t) node with constraints on rate and distortion is

$$\boldsymbol{w_r(p(s,t) \overset{\text{def}}{=} \sum_{\substack{(i,j)\epsilon p(s,t) \\ \forall(1,\ldots\ldots,R)}} w_r\,(i,j) \le c_r(s,t)} \qquad (3)$$

A* search algorithm [7-8] with proper pruning technique is used to solve K-MCSP problem defined in Eq.3 where K is any positive integer. In this paper, five best feasible multiple constraints shortest paths are found with two constraints i.e DVF and DFD.

4. Experimental Analysis of K-MCSP Using Improved Quad Tree with A* Prune Algorithms

Extensive experimental results have been carried out on several test sequences such as Mother Daughter and Foreman for improved quad tree algorithm with variable threshold on edges. Displacement field difference (DFD) i.e distortion and displaced vector field (DVF) i.e rate are calculated for each block size 16*16, 8*8 and 4*4 respectively. The

DVF are calculated using exhaustive/full search for motion estimation and motion vectors are coded with DPCM technique. Displacement field difference (DFD) is coded with Huffman entropy coding. The performance of proposed approach is evaluated using extensive experimental simulation conducted on a 2.0 GHZ PC with 2 GB main memory with MATLAB. The efficiency of improved algorithm is performed using PSNR, Total coded bits and average computational complexity. The video sequences taken for experimental simulation is listed below in Table 1 with its motion characteristics.

Table 1: Video sequences taken for experimental simulation with variable motion

Name of Video Sequence	Type of video format	Motion Characteristics	Resolution
Foreman	QCIF	Background is static but objects are moving with large motion.	176×144
Mother Daughter	CIF	The background is static but objects movement is very small, blocks are mostly quasi stationary.	352×288

It is shown from the experimental simulation that the performance can be dramatically improved by reducing the bits requirement for encoding the motion vectors and allocating the data bits to the residual encoding, which eventually improves the quality of the picture. With very low bit rate applications this coding strategy proves to be very advantageous. The number of bits required for DFD and DVF for each of the K shortest paths is computed along with the corresponding PSNR values. The best of the shortest path is selected for reconstruction of the frame in our study. Table 1, Table 2 and Table 3 show multiple constraint shortest paths for two different test sequence with their rate (DVF), distortion (DFD), PSNR and computational complexity with and without improved quadtree algorithms for motion estimation respectively.

The constraints for both Rate and distortion as per our A* prune algorithm to given values below:

K: 5	DVF constraints: 20000	DFD constraints: 20000	Count: 24334	List Size: 10

Table 2: DVF-DFD values for frame -2 at Block Size=16, 8 and 4 and QP=16, 32, 64 with improved and traditional quadtree algorithms for Foreman Video sequence

Block Size	**16**	**8**	**4**
DVF	1577	1574	1928
DFD	7624	12396	17644
Total Bits	9201	13970	19572
PSNR	20.8078	20.4887	20.5158

Table3: DVF-DFD values for K-paths for frame-5 at QP=64

K-paths →	**1**	**2**	**3**	**4**	**5**
Metrics parameter ↓					
DVF	1577	1625	1637	1673	1757
DFD	7624	7576	7565	7535	7479
Total bits	9201	9201	9202	9208	9236
PSNR	20.8078	20.8002	20.8002	20.7607	20.7587
Time Complexity (ms)	24.3367	24.8929	25.4652	26.0755	26.7320
Time for Quad-tree loop (ms)	6.5918				

Table 2 shows that both DVF and DFD satisfy required the constraints set for rate and distortion respectively. Only five feasible paths are obtained for the given constraints. The total bits and PSNR are shown for each path. It is concluded from Table 3 that all the paths provided by improved algorithm are feasible solutions, and do not violate the limitation imposed on the constrained. Figure 3 shows the original and reconstructed frame along with quadtree structure of foreman video sequence constructed by improved quadtree algorithm.

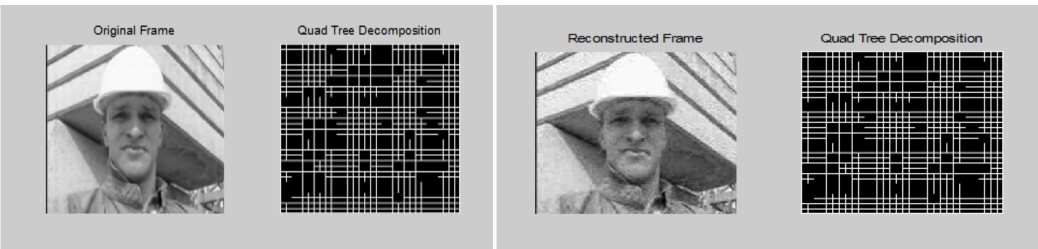

Fig. 3: Original and Reconstructed Frame 5 of Foreman Video Sequence for path 3 for improved quadtree algorithms

Similarly, Table 4 shows that both DVF and DFD satisfy required the constraints set for rate and distortion respectively for mother daughter frame. It is clearly shown from Table 5 that five feasible paths are obtained for the given constraints using our improved quadtree compared to only three paths in traditional quadtree algorithm.

Table 4: DVF-DFD values for frame -2 at Block Size=16, 8 and 4 and QP=16, 32, 64 with improved and traditional quadtree algorithms for Foreman Video sequence

Block Size	**16**	**8**	**4**
DVF	614	920	1604
DFD	578	5599	19969
Total Bits	1192	6519	21573
PSNR	34.1227	34.1227	34.1227

Table 5: DVF-DFD values for K-paths for frame-5 at QP=64

K-paths → / **Metrics parameter** ↓	**1**	**2**	**3**	**4**	**5**
DVF	614	626	644	662	686
DFD	578	564	546	531	515
Total bits	1192	1190	1190	1193	1201
PSNR	34.1227	34.1227	34.1229	34.1229	34.1229
Time Complexity (ms)	30.4023	31.1381	31.9158	32.7887	33.8059
Time for Quad-tree loop (ms)	7.5918				

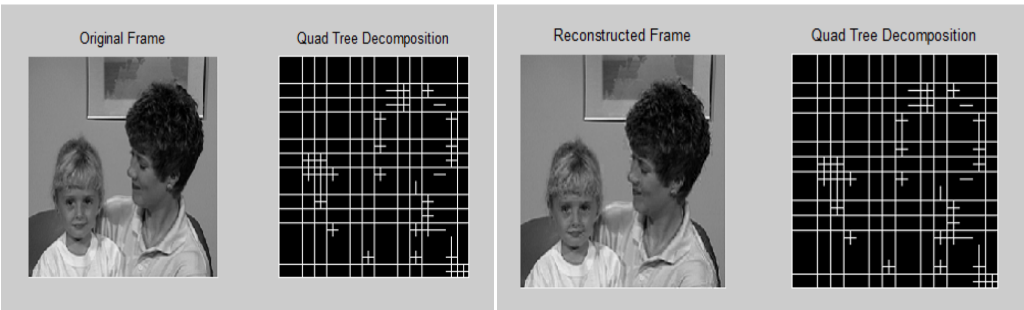

Fig. 4: Original and Reconstructed Frame 5 of Mother Daughter Video Sequence for path 3 using improved quadtree algorithm

Fig. 5 shows the residual frame after subtracting reconstructed frame and original frame Mother Daughter Video Sequence for given constraints.

Fig. 5: residual frame after subtracting reconstructed frame and original frame Mother Daughter Video Sequence

Conclusion:

In order to reduce the computational requirement of the encoder, many researchers have focused in the area typically acknowledging the fact motion estimation typically represents around 70 to 90% of an entire encoder computational requirement. In this paper, an attempt has been made to introduce a computationally efficient improved quadtree algorithms for motion estimation with multiple constraints on rate and distortion imposed. Lagrange multiplier optimization technique is used for minimizing the sum of distortion of block and 'λ' times bits needed to code it, where 'λ' is the Lagrangian parameter. The pruning /merging motion estimation algorithm which is based on the philosophy of quad tree structure leads to substantial improvement in the quality of the reconstructed picture without much distortion and is also significantly helpful in reducing the computational requirements as shown in Fig.3and Fig. 4 respectively. A* prune algorithm for multiple constrained shortest path is used for variable size block matching technique which generates lower overall bit rates without compromising both DVF and DFD constraints simultaneously and satisfying both as well.

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INNOVATIONS IN PEROVSKITE SOLAR CELLS DRIVING HIGH-PERFORMANCE ENERGY STORAGE

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Abstract:

Perovskite solar cells (PSCs) have emerged as a promising technology for high-performance energy storage devices due to their exceptional photovoltaic properties, including high power conversion efficiency (PCE), tuneable band gaps, and cost-effective fabrication. Recent advancements have focused on improving the stability, efficiency, and integration of PSCs with energy storage systems such as lithium-ion batteries, super capacitors, and hybrid devices. Innovations in material engineering, interface optimization, and device architecture have significantly enhanced the PCE, surpassing 25%, while also addressing issues related to moisture, thermal stability, and long-term performance. Additionally, the development of perovskite-based photo-rechargeable systems has opened new avenues for sustainable and efficient energy solutions. This review highlights recent progress in PSC technology, emphasizing strategies to overcome existing challenges and discussing their potential applications in next-generation high-performance energy storage devices.

Keywords: Perovskite Solar Cells, Energy Storage Devices, High Performance, Power Conversion Efficiency, Stability, Material Engineering, Photo-Rechargeable Systems.

1. Introduction:

Perovskite solar cells (PSCs) have emerged as a revolutionary photovoltaic technology due to their remarkable power conversion efficiency (PCE), low-cost fabrication, and tunable optoelectronic properties. Since their inception, PSCs have attracted significant attention from researchers aiming to develop efficient and sustainable energy solutions. With PCE values now exceeding 25%, PSCs have demonstrated tremendous potential in the field of solar energy harvestin [1-5]. Beyond traditional applications, recent advancements have extended the use of PSCs into high-performance energy storage devices. Integrating PSCs with energy storage technologies, such as lithium-ion batteries, supercapacitors, and hybrid systems, has opened new possibilities for developing self-powered and photo-rechargeable energy storage systems. This integration addresses the increasing demand for efficient energy management and provides a sustainable pathway to meet global energy requirements [6-9]. Despite remarkable progress, challenges remain in achieving long-term stability, scalability, and compatibility between PSCs and energy storage components. Innovative material engineering, interface optimization, and device architecture improvements are critical to overcoming these limitations and advancing PSC-based energy storage applications [10-13]. This paper reviews recent developments in PSCs for high-performance energy storage devices, focusing on advancements in materials, device integration strategies, and the challenges associated with enhancing efficiency and stability. By highlighting current trends and future perspectives, this review aims to provide insights into the potential of PSCs as a key component in next-generation energy storage technologies [14-17].

2. Organic Solar Cell

Enas Moustafa *et al.* [18] studied the impact of interfacial layers on the performance and scalability of organic solar cells (OSCs). Many interface materials face limitations in fabrication temperature and stability for large-scale production. This research analyzed fresh and photo-aged inverted non-fullerene OSCs (INF-OSCs) with different electron transport layers (ZnO, ZnO/PDINO, and PDINO), focusing on their optical and electronic properties. The results showed that PDINO is an effective low-temperature cathode interlayer for INF-OSCs, offering superior photo stability almost three times better than ZnO-based devices under continuous AM 1.5G (100 mW cm^2) illumination. This enhanced stability is due to PDINO's lack of photochemical reactions with the PM6:Y7 photoactive layer, avoiding the photo catalytic effect seen with ZnO.Lingpeng Yan *et al.* [19] demonstrate that while zinc oxide nanoparticles (ZnO NPs) are ideal electron transport materials for high-efficiency organic solar cells (OSCs), their surface defects and catalytic properties pose challenges. To address this, they synthesize carbon-coated ZnO nanoparticles (ZnO@C NPs). The carbon shell enhances hydrophobicity, UV absorption, and surface passivation, reducing defects, water, and oxygen adsorption, and preventing hydroxyl radical formation. As a result, ZnO@C-based PM6:L8-BO OSCs achieve a power conversion efficiency of 17.55%, surpassing ZnO-based devices (16.92%). These OSCs also show improved air and UV stability, highlighting the potential of ZnO@C NPs for efficient, stable, and durable OSCs.Bharti Sharma *et al.* [20] reported that the Power Conversion Efficiency (PCE) of Organic Solar Cells (OSCs) is significantly influenced by the Transparent Conductive Electrode (TCE). ITO, the most common TCE, hinders performance on flexible plastic substrates due to brittleness and cracking under stress. Therefore, alternative TCEs are needed. Carbon nanotubes (CNTs) are promising due to their high optical transparency, low sheet resistance, and high mobility. This study uses SCAPS 1-D software to simulate NFA-BHJ-OSC performance with CNTs doped with Molybdenum trioxide (MoO3) as a transparent electrode. The optimized results show a PCE of 22.71%, Fill Factor (FF) of 63.14%, Jsc of 38.38 mA/cm^2, and Voc of 0.9371 V by adjusting the band gap of MoO3-doped CNTs. Furthermore, using CuSCN as a hole transport layer (HTL) yields the best performance, with a PCE of 27.57%, FF of 70.88%, Jsc of 37.12 mA/cm^2, and Voc of 1.0477 V. These findings highlight the potential of CNT-based TCEs to enhance OSC performance. David J *et al.* [21] reported that metal-organic framework nanosheets (MONs) are promising 2D materials with tunable chemistry for sensing, catalysis, electronics, and separation. However, scalable synthesis of high-quality, ultrathin MONs remains challenging, with limited focus on economic viability. This study presents a scalable synthesis of zinc-porphyrin-based nanosheets ($Zn_2(H_2TCPP)$) for organic solar cells and a technoeconomic analysis of pilot-scale production. By optimizing solvothermal synthesis, including adding triethylamine to reduce temperature from >80°C to room temperature, they achieved a 99% yield of monolayer MONs with a space–time yield of 16 kg/m^3/day—a 20-fold increase compared to literature methods. Cost analysis showed a 94% reduction compared to traditional synthesis, mainly due to ligand cost. The method's versatility was demonstrated by synthesizing $Cu_2(H_2TCPP)$ MONs and tuning porphyrinmetalation with six metal ions. Incorporating MONs into organic photovoltaic devices nearly doubled the power conversion efficiency, marking the first scalable, sustainable production of monolayer nanosheets for high-value applications.

Xiaojun Li *et al.* [22] reported that the active layer of organic solar cells (OSCs) consists of a p-type conjugated polymer (donor) and an n-type organic semiconductor (acceptor). Since 1995, fullerene derivatives like PCBM and PC71BM have dominated OSCs as acceptors. In 2015, A–D–A structured small molecule acceptors (SMAs) emerged, offering narrow bandgaps, strong long-wavelength absorption, and suitable energy levels, boosting PCE to 10–14%. With the innovation of A–DA'–D–A SMAs, the PCE of OSCs has risen from 15% to 19%. This review covers the development of n-type organic semiconductor acceptors, including fullerene derivatives and narrow bandgap SMAs, highlighting their molecular structures, properties, and the impact of molecular packing and miscibility on performance. Current challenges and future prospects are also discussed. Michael S.A. Kamel *et al.* [23] demonstrated that transfer-free graphene transparent conducting electrodes (TCEs) are a promising alternative to ITO for organic solar cells (OSCs). This study investigated how deposition temperature and H_2 flow rates influence the growth, structural, optical, and electrical properties of graphene produced by RF plasma-enhanced chemical vapor deposition (RF-PECVD) using sustainable sources.OSC devices with a P3HT:PCBM photoactive layer were fabricated on graphene TCEs produced under various conditions. Hybrid graphene-AgNW TCEs were also examined. Results showed that graphene TCEs prepared at low or zero H_2 flow outperformed those made with high H_2 flow. Additionally, high-temperature growth (>700°C) on quartz led to poorer performance due to increased vertically oriented graphenenanosheets, reducing transmittance and increasing roughness. This work optimizes the sustainable, cost-effective production of transfer-free graphene TCEs for OSCs, promoting ITO-free optoelectronics. Souhardya Bera *et al.* [24] reported that third-generation solar cells are gaining popularity due to their eco-friendliness, easy fabrication, high efficiency, and low commercialization cost. Metal-Organic Frameworks (MOFs), known for their porosity and high surface area, are promising for solar cell fabrication. This review compiles various MOF structures for high-performance solar cells. While pristine MOFs have been used as photoanodes in Dye-Sensitized Solar Cells (DSSC), their insulating nature and poor charge transport limit efficiency. They also struggle as counter electrodes due to low conductivity. However, MOFs enhance crystallinity and stability in Perovskite Solar Cells (PSC). The article details MOF-derived materials for DSSC and PSC, highlighting their light-harvesting potential and tunable crystal frameworks. Although MOF-based fabrication is still emerging, this paper offers insights into photovoltaic applications and MOF diversification, addressing existing challenges and potential improvements. Binling Chen *et al.* [25] emphasized that harnessing natural energy, especially solar energy, is crucial for achieving a carbon-neutral future. Solar energy, abundant and renewable, can meet global energy needs, but developing cost-effective and durable materials for efficient energy conversion remains challenging. Solar cells, as key photovoltaic devices, efficiently convert sunlight to electricity. Metal-Organic Frameworks (MOFs) and their derivatives, known for their unique morphology, physicochemical properties, and porous structure, have shown significant potential in enhancing solar-to-electricity conversion and stability. This review discusses the latest advancements in using MOFs and their derivatives in solar cells, including dye-sensitized, perovskite, and organic types. It covers material composition, synthesis, device processing, and photovoltaic performance. The roles of MOFs as electrodes, photoactive materials, charge carriers, and additives are highlighted, along with challenges and future directions. Nikolaos Felekidis *et al.* [26] explored how mixing different compounds enhances the functionality of organic electronics. They quantified how charge transport properties in mixed materials differ from the sum of individual properties. In bulk heterojunction organic solar cells, the hole mobility in the donor phase significantly depends on the chosen acceptor, affecting the donor's energetic disorder. Similarly, electron mobility in the acceptor varies based on the donor. These mobility changes can exceed an order of magnitude compared to pristine materials. By applying a state-filling model for the open-circuit voltage (VOC) of ternary D:A1:A2 organic solar cells, they demonstrated a nearly linear 40enability of VOC with the A1:A2 weight ratio. The study predicts that selecting optimal donor-acceptor pairs in binary OPV systems could increase PCE, e.g., from 11% to 13.5%, underscoring the importance of strategic material combinations.

Marja Vilkman *et al.* [27] emphasized that understanding interface phenomena is key to enhancing efficiency and stability in flexible organic solar cell modules. Minimizing energy barriers ensures efficient charge transfer, while good adhesion improves mechanical stability and lifespan. This study used an inverted organic solar module stack with standard photoactive materials (P3HT:PCBM) to investigate interfaces in a roll-to-roll (R2R) process. Results showed that controlling the adhesion and work function of the ZnO nanoparticle-based electron transport layer in the R2R process improves performance and lifespan. Plasma treatment of ZnO nanoparticles and oxygen trapping during encapsulation increased the ZnO work function, creating energy barriers and an S-shaped IV curve. Light soaking restored the work function, achieving PCEs above 3%. Post-printing plasma treatment effectively removed organic ligands, boosting adhesion and extending module life. Treated modules maintained 80% efficiency for ~3000 h in accelerated tests, compared to less than 1000 h without treatment. Dong-Jin Yun *et al.* [28] studied RuO_2 films deposited on SiO_2/Si substrates via RF magnetron sputtering at room temperature. After deposition, films were annealed at various temperatures (100, 300, 500 °C) in different atmospheres (Ar, O_2, vacuum). While the annealing atmosphere had minimal impact, higher temperatures significantly improved resistivity and crystallinity. To assess RuO_2 as alternative electrodes in flexible devices, both as-deposited and annealed films were used as source/drain electrodes in OTFTs, catalytic electrodes in DSSCs, and hole-injection buffer layers in OPVs. Annealed RuO_2 electrodes outperformed as-deposited ones, with DSSC and OPV efficiencies increasing from 3.0% to 3.5% and 1.61% to 2.56%, respectively. OTFTs with RuO_2 S/D electrodes maintained good performance ($\mu \approx 0.45$ cm^2/Vs, on/off ratio $\approx 5\times10^5$). Huei-Ting Chien *et al.* [29] focused on the stability of organic photovoltaic (OPV) cells after achieving efficiencies above 10%. While incorporating a hole-transport layer (HTL) enhances efficiency, the commonly used PEDOT:PSS HTL often causes instability due to photooxidation and electrode corrosion. Identifying degradation sources is challenging as oxygen and moisture affect multiple components. This study compared PEDOT:PSS and two types of MoO_3 HTLs exposed to oxygen, light, or humidity before device finalization. Results showed that humidity exposure reduced performance for PEDOT:PSS and one MoO_3 variant, primarily due to absorbed water causing swelling and reduced interfacial contact. Devices with PEDOT:PSS exhibited severe photocurrent loss, while water-based MoO_3 showed slight decay. In contrast, the alcohol-based MoO_3 HTL maintained stable performance, highlighting its potential for durable OPVs. Yongxi Li *et al.* [30] developed a near-infrared (NIR) organic photovoltaic (OPV) cell with high open-circuit voltage (Voc) and external quantum efficiency (EQE), addressing a key challenge in achieving PCE > 15%. The solar cell, based on a chlorinated nonfullerene acceptor with a small energy gap (1.3 eV), achieved a PCE of 11.2%, short-circuit current of 22.5 mA/cm^2, Voc of 0.70 V, and fill factor of 0.71—the highest for NIR single-junction OPVs. Notably, the EQE reached 75% between 650 and 850 nm, with a transparency window from 400 to 600 nm. A semitransparent version with a 10 nm Ag cathode showed a PCE of 7.1% and an average visible transmittance of 43%. Mehrad Ahmadpour *et al.* [31] introduced crystalline molybdenum oxide (MoOx) layers that outperform conventional thermally grown MoOx in organic photovoltaic (OPV) devices. These high work function hole contact layers are derived from superoxidized MoO3.2 films, grown via reactive sputtering and crystallized through high-vacuum annealing. OPV devices with DBP as the donor and C70 as the acceptor showed increased power conversion efficiency with higher MoOx annealing temperatures, unlike thermally deposited MoOx. The crystalline MoOx exhibited enhanced conductivity and stability, making it a promising hole contact material for durable organic optoelectronics. Fenggui Zhao *et al.* [32] highlighted the potential of combining organic-inorganic hybrid perovskites (OIHP) and non-fullerene acceptors (NFA) in photovoltaics. They developed a novel method to improve efficiency and stability in NFA organic solar cells by integrating tin oxide (SnO_2) with $MAPbI_3$ perovskite nanowires (PeNWs) at the interface. This structure (ITO/SnO_2/PeNWs/PBDB-T-SF:IT-4F/MoO_3/Ag) enhanced electron-hole dissociation, charge extraction, and photo-absorption. The resulting solar cell maintained over 80% power conversion efficiency (PCE) after 20 days, demonstrating the effectiveness of combining SnO_2 and PeNWs.Zhi Chen *et al.* [33] investigated the effect of the resistance of solution-processed ZnO interlayers on organic solar cell performance. They found that UV-induced doping significantly lowers ZnO resistance, causing an overestimation of the photoactive area and short-circuit current density (Jsc) when measured without an aperture. This issue can arise unintentionally during fabrication and characterization due to UV exposure from solar simulators or light sources. They demonstrated that high-resistance interlayers could still overestimate Jsc, emphasizing the need for careful evaluation. Jakob Hofinger *et al.* [34] studied voltage losses in high-performance non-fullerene acceptor (NFA) based solar cells, aiming to close the efficiency gap with inorganic photovoltaics. They focused on D18:Y6 organic solar cells with a PCE of 16%, revealing a low voltage loss of 0.51 V, significantly lower than the 0.8 V loss in fullerene-based D18:PC71BM devices. The reduced loss in Y6-based cells is attributed to the high charge transfer state energy and strong emissivity of the pristine acceptor. The study suggests design strategies to further enhance OPV performance.

3. Dye-Sensitized-Solar Cells (DSSCs)

K. Inbarajan *et al.* [35] investigated the use of textile dye effluents as sensitizers in Dye-Sensitized Solar Cells (DSSCs). Blue and green dye mixtures from small-scale industries, containing chemicals (H5G, H7GL) with soda ash (NaCO) and salt (NaOH), were tested. The DSSCs made with blue and green dyes showed efficiencies of 0.054% and 0.015%, respectively, demonstrating the potential of utilizing industrial dye effluents in DSSC technology. Hui Song *et al.* [36] developed glass-free TiO_2 photoelectrodes for DSSCs using a transfer method with sacrificial ZnO nanorods. The TiO_2 layer was formed on ZnO nanorods via doctor-blading and calcination, followed by adhesion to an Ag epoxy film on a PET substrate. The ZnO was selectively etched to produce the glass-free electrode. The resulting DSSC, using a Pt-coated conductive PET counter electrode, achieved a power conversion efficiency of 4.8% and a short-circuit current of 18.06 mA/cm^2.Guanglu Shang *et al.* [37] synthesized mesoporous tin oxide spheres (MS-SnO_2) ranging from 100 to 800 nm via a simple solution method. These spheres, made of packed nanocrystals, have a specific surface area of 29.4 m^2/g and a pore size of about 4 nm. Due to their large size, high surface area, and good intercrystalline connections, DSSCs using MS-SnO_2 film photoanodes achieved a higher efficiency of 4.97% compared to conventional SnO_2 nanoparticle photoanodes. The efficiency was further improved by adding a TiO2 blocking layer and performing $TiCl_4$ post-treatment.

Jihuai Wu *et al.* [38] synthesized a tungsten sulfide/multi-wall carbon nanotube (WS2/MWCNT) hybrid using glucose via a hydrothermal method. This hybrid served as a counter electrode in dye-sensitized solar cells (DSSCs). Electrochemical analysis showed that the glucose-aided (G-A) WS2/MWCNT electrode had low charge-transfer resistance and high electrocatalytic activity for triiodide reduction. The improved performance is attributed to the synergy between WS2, MWCNTs, and amorphous carbon from glucose. The DSSC with the G-A WS2/MWCNT electrode achieved a power conversion efficiency of 7.36%, comparable to the Pt electrode (7.54%). Won Jae Lee *et al.* [39] demonstrated the use of multiwall carbon nanotubes (CNTs) as electrocatalysts for triiodide reduction in dye-sensitized solar cells (DSSCs). The defect-rich edge planes of bamboolike multiwall CNTs enhance electron transfer at the counter electrode-electrolyte interface, reducing charge-transfer resistance and improving the fill factor. The CNT-based DSSC, combined with a TiO2 photoanode and organic liquid electrolyte, achieved 7.7% efficiency under 1 sun illumination. Short-term stability tests confirmed the robustness of the CNT counter-electrode DSSCs.Anurag Roy *et al.* [40] investigated the color comfort of N719 dye-sensitized TiO2-based DSSC BIPV windows after 2 years of ambient exposure. Three DSSCs with varying TiO2 thickness were fabricated. Results showed reduced average visible transmission but improved color properties in all cases. This study highlights the potential of DSSC-based BIPV windows for long-term use, focusing on color rendering index (CRI) and correlated color temperature (CCT). Yogendranath Chouryal *et al.* [41] demonstrated the potential of upconverting nanoparticles to enhance solar cell efficiency. They synthesized cubic BaGdF:Er/Yb nanocrystals using ionic liquids and combined them with TiO_2 as the absorption layer in DSSCs. Bright green (520, 540 nm) and red (665 nm) emissions indicated a two-photon absorption process. DSSCs with the BaGdF:Er (1%)/Yb (10%)/TiO_2 layer achieved a PCE of 7.75% and current density of 15.9 mA/cm^2, showing a 68.47% efficiency improvement compared to TiO_2-only devices. This highlights the potential of upconverting materials in solar cells. Liang Li, YuLin Yang *et al.* [42] developed a novel photoanode material for DSSCs by loading TiO_2 on K6SiW11O39Co(II)•xH_2O (SiW11Co). The resulting TiO_2@SiW11Co material extends light absorption to the visible range and enhances UV absorption compared to P25 (raw TiO_2), while also preventing TiO_2 network recombination. DSSCs using a TiO_2@SiW11Co and P25 mixture (1:1) with N719 dye achieved a short-circuit photocurrent density of 18.05 mA/cm^2, a 64% increase compared to blank samples under standard solar irradiation. Mechanisms of SiW11Co in DSSCs are also discussed. Hongcai He *et al.* [43] developed multifunctional composite nanocables (CNCs) with a thermoelectric $NaCo_2O_4$ core and TiO_2 shell via electrospinning and annealing, used as photoanodes in DSSCs. Incorporating 10 wt% CNCs in the TiO_2 photoanode increased the PCE to 9.05%, compared to 7.47% with pure TiO_2. The enhanced performance is attributed to the thermoelectric effect from temperature gradients caused by sunlight irradiation. A gradient of ±5 K led to PCE changes of 10.07% and 7.76%, respectively, highlighting the impact of thermoelectric force direction. This approach integrates photovoltaics and thermoelectricity for improved energy efficiency. Kyung Chul Sun *et al.* [44] demonstrated that one-dimensional TiO_2 nanotubes enhance light scattering, light harvesting, and electron transport in DSSCs, boosting performance. Pure anataseTiO_2 nanotubes were synthesized via a cost-effective hydrothermal method using P25. To increase power conversion efficiency, a double-layered photoanode was developed, combining TiO_2 nanoparticles as the main layer and TiO_2 nanotubes (TNT) as the over-layer. The TNT over-layer improved electron lifetime, surface area, pore volume, and light harvesting efficiency by 40%. This optimized structure supports the advancement of next-generation DSSCs. Leila JafariForuzin *et al.* [45] synthesized a TiO_2@ZnAl-layered double hydroxide nanocomposite via co-precipitation, followed by calcination to obtain TiO_2@MMO. Characterization techniques (SEM, XRD, TGA, FT-IR, UV-vis DRS) confirmed the structure. Used as a photoanode in DSSCs, it showed higher conversion efficiency compared to ZnAl-layered double hydroxide, attributed to increased surface area and dye adsorption. Reducing film thickness (4.72 mm) improved open-circuit voltage, reduced recombination, and enhanced solar cell efficiency.

Mohd Jahir Khan *et al.* [46] developed a dye-sensitized solar cell (DSSC) using nanoengineered diatom-Si–TiO_2 structures (DsTnas-DSSC), with a TiO_2-based photoanode and a graphene oxide-coated cathode. Natural dyes from plants and microalgae were compared with synthetic ruthenium dye. The highest power density (PDmax) was achieved with ruthenium dye (9.4%), followed by astaxanthin from *Haematococcuspluvialis* (7.19%).

The natural dye-based DsTnas-DSSC offers a cost-effective alternative to conventional DSSCs.Jia-De Peng *et al.* [47] synthesized mono-dispersed TiO_2 microspheres with highly exposed (001) facets (82%), high surface area (112.2 m^2/g), and a self-ordered 3D porous network via an *in-situ* facet-controlling method. These microspheres, used as photoanodes in dye-sensitized solar cells (DSSCs), exhibit efficient dye loading and electrolyte diffusion due to their porous structure. The DSSC achieved a high photoelectric conversion efficiency of 11.13% under 100 mW/cm^2 light, outperforming conventional TiO_2 film (8.11%). These TiO_2 microspheres are promising for use in high-performance DSSCs, photocatalysis, water splitting, and lithium-ion batteries. PrasenjitKar *et al.* [48] demonstrated the impact of surface plasmon resonance (SPR) of noble metals on electron injection efficiencies in dye-sensitized solar cells (DSSCs). Au nanoparticles (SPR peak at 560 nm) showed enhanced photoinduced electron transfer (PET) from the dye to the TiO_2 matrix compared to Al nanoparticles. A DSSC fabricated with Au–Al nanoparticles and N719 dye achieved a higher power conversion efficiency (7.1%) compared to TiO_2 alone (5.63%), attributed to plasmonic coupling and scattering effects. AnusuyaSahaab *et al.* [49] proposed a sigma-bridged framework as spacers for dye-sensitized solar cells (DSSCs) to prevent π–π aggregation on the semiconductor surface. The norbornylogous bridged spacer, exhibiting electron propagation through sigma and π orbital interactions, demonstrated promising optical properties. Density functional theory (DFT) calculations with the designed dyes showed improved optical parameters compared to conventional π-conjugated thiophene spacers. Notably, the trans-sesquinorbornatriene system spacer (6-D) exhibited a high VOC of 3.3 eV, ΔGinjection of 2.4 eV, and oscillatory strength of 0.96, indicating effective exciton dissociation and enhanced DSSC performance. Xiyun Tao *et al.* [50] developed TiO2 mesoporousnanosheet microspheres via a hydrothermal process, achieving a hierarchical anatase structure with enhanced photoelectric properties for dye-sensitized solar cells (DSSCs). The well-dispersed TiO2 microspheres (2 μm) exhibited high light scattering and dye absorption due to exposed (101) facets. Incorporating these microspheres into the top scattering layers of quasi-solid-state DSSCs improved power conversion efficiency to 7.51%, a 45.8% increase compared to spine hierarchical TiO2 (5.15%), highlighting their potential for stable, high-efficiency DSSCs. GülenayTunç *et al.* [51] synthesized asymmetric zinc phthalocyanine dyes with electron-donating tert-butylsulfanyl or hexylsulfanyl groups and a carboxylic acid anchor for dye-sensitized solar cells (DSSCs). Theoretical calculations indicated that GT4 isomers exhibited a red-shift compared to GT6, while GT6 showed better photostability due to its non-planar structure. DSSCs using GT4 and GT6 with chenodeoxycholic acid (CDCA) as a co-adsorbent achieved power conversion efficiencies (PCE) of 3.19% and 3.08%, respectively, with GT6 retaining optical properties after sunlight exposure, highlighting its stability advantage. PousaliChal *et al.* [52] synthesized PANI–PTCDA composites by in situ polymerizing aniline with varying PTCDA concentrations (9.8%, 13.1%, and 21.3%) to form P10, P15, and P20, respectively. The composites retained PANI's nanotubular morphology with new hairy surfaces. Characterization showed π-stacking interaction between PANI and PTCDA, with blue shifts indicating H-aggregate formation. Among the composites, P15 exhibited the highest DC-conductivity (1.1 × 10−2 S cm−1) and reversible photocurrent. DSSCs with N719 dye and P15 achieved the highest PCE of 2.88%, with an IPCE of up to 52% between 360–660 nm. Nyquist plots revealed that P15's optimized resistance and capacitance at the PANI–PTCDA/electrolyte interface resulted in a higher lifetime and reduced back-reaction, enhancing PCE.

Khalid Mahmood *et al.* [53] developed a dye-sensitized solar cell (DSSC) using a double light-scattering-layer boron-doped ZnO (DL-BZO) film, achieving a high energy conversion efficiency of 7.2%. The DL-BZO film consists of a submicrometer-sized boron-doped ZnO (BZO) sphere array over-layer, enhancing electron transport and light scattering, and a nanoporous BZO nanoparticulate under-layer that increases dye adsorption and reduces electron recombination. The DL-BZO film outperformed undoped ZnO (4.1%) and monolayer NP-BZO films (2.1%) due to improved light harvesting, larger surface area, and slower electron recombination. The cell maintained high stability over 35 days, marking the highest efficiency reported for double-layer ZnO film-based DSSCs. Katarzyna Pydzińska *et al.* [54] studied the impact of modifying mesoporoustitania layers on perovskite solar cells (PSC) and dye-sensitized solar cells (DSSC). For PSC with triple cation perovskite, a more homogeneous, larger particle (30 nm), and thinner (150–200 nm) titania layer increased the photocurrent by 40% (up to ~24 mA/cm^2). In DSSCs (liquid cobalt-based and solid-state with spiro-OMeTAD), diluted titania paste (2:1 w/w) improved dye loading, photovoltage, and photocurrent compared to undiluted paste. Femtosecond transient absorption revealed faster electron transfer in improved PSC and slower unwanted recombination in liquid DSSCs. In solid-state DSSCs, efficient hole injection from MK2 dye to spiro-OMeTAD was observed, facilitated by better spiro-OMeTAD penetration in thinner, porous layers.

Table 1: Perovskite Solar Cells composition and their preparation methods.

S. No	Material Composition	Preparation Method	Power Conversion Efficiency	Rf
1	INF-OSCs	Low-temperature Method	-	[[18]
2	ZnO NPs	-	17.55%	[19]
3	MoO3	-	-	[20]
4	$Zn_2(H_2TCPP)$	>80°C	-	[21]
5	PC71BM	-	-	[22]
6	AgNW TCEs	(>700°C	-	[23]
7	P3HT:PCBM		80%	[27]
8	RuO_2	100, 300, 500 °C	-	[28]
9	MoOx	Higher-temperature	High efficiency	[31]
10	$ITO/SnO_2/PeNWs/PBDB$-T-$SF:IT$-$4F/MoO_3/Ag$	-	80%	[32]
11	H5G, H7GL	-	0.054%	[35]
12	TiO2	-	4.8%	[36]
13	MS-SnO2	-	4.97%	[37]
14	WS2/MWCNT	-	7.36%	[38]
15	CNTs	-	7.7%	[39]
16	BaGdF:Er/Yb	-	68.47%	[41]
17	TiO_2	-	40%	[44]
18	TiO_2@ZnAl,TiO_2@MMO	-	-	[45]
19	Si–TiO_2	-	9.4%	[46]
20	DSSCs	-	11.13%	[47]
21	SPR	-	7.1%	[48]
22	CDCA	-	3.19% and 3.08%	[51]
23	PTCDA	-	9.8%, 13.1%, and 21.3%	[52]
24	ZnO (DL-BZO)	-	7.2%	[53]
25	spiro-OMeTAD	-	40%	[54]

Conclusion:

Organic solar cells (OSCs) and dye-sensitized solar cells (DSSCs) have emerged as promising alternatives to conventional photovoltaic technologies due to their lightweight nature, flexibility, cost-effective fabrication, and tunable optoelectronic properties. OSCs have seen significant advancements in donor-acceptor materials, device engineering, and efficiency improvements, while DSSCs continue to benefit from innovations in dye molecules, electrolytes, and electrode materials. Despite their potential, challenges such as stability, scalability, and efficiency limitations remain key hurdles for widespread commercialization. Continued research efforts focusing on material optimization, interface engineering, and stability enhancement will be crucial in advancing OSCs and DSSCs toward practical applications. With ongoing progress, these solar technologies hold great promise for contributing to the global shift toward sustainable and renewable energy solutions.

Acknowledgment:

The author Dr. T. Rajesh Kumar would like to acknowledgment the Department of Chemistry, AMET University for valuable support for completion of this work.

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A STUDY ON FIBONACCI NUMBERS AND ITS APPLICATIONS IN ENGINEERING SCIENCE

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Abstract:

Fibonacci series, where the number is combined with the two that precede it to generate the subsequent number within the sequence, can be found throughout life and is best described by its ubiquity. It appears in repetitive natural formations such as leaf grouping, banded tree branches, flower and shell spirals and utilizes the golden ratio to accomplish the purpose of trying to optimize space and utilization of resources. In computer science, the sequence has applications in data structures and algorithms like Fibonacci heaps and search algorithms and as a learning example for recursion and dynamic programming. In architecture, Fibonacci numbers are used to discover design proportions and design structurally stable and aesthetically pleasing buildings with natural symmetry. This trans disciplinary presence reaffirms the relevance of the Fibonacci sequence to represent efficiency, balance, and beauty in nature and human technology.

Keywords: Fibonacci Series, Natural Formations, Data Structures, Architecture, Flower Spirals, Golden Ratio

Introduction:

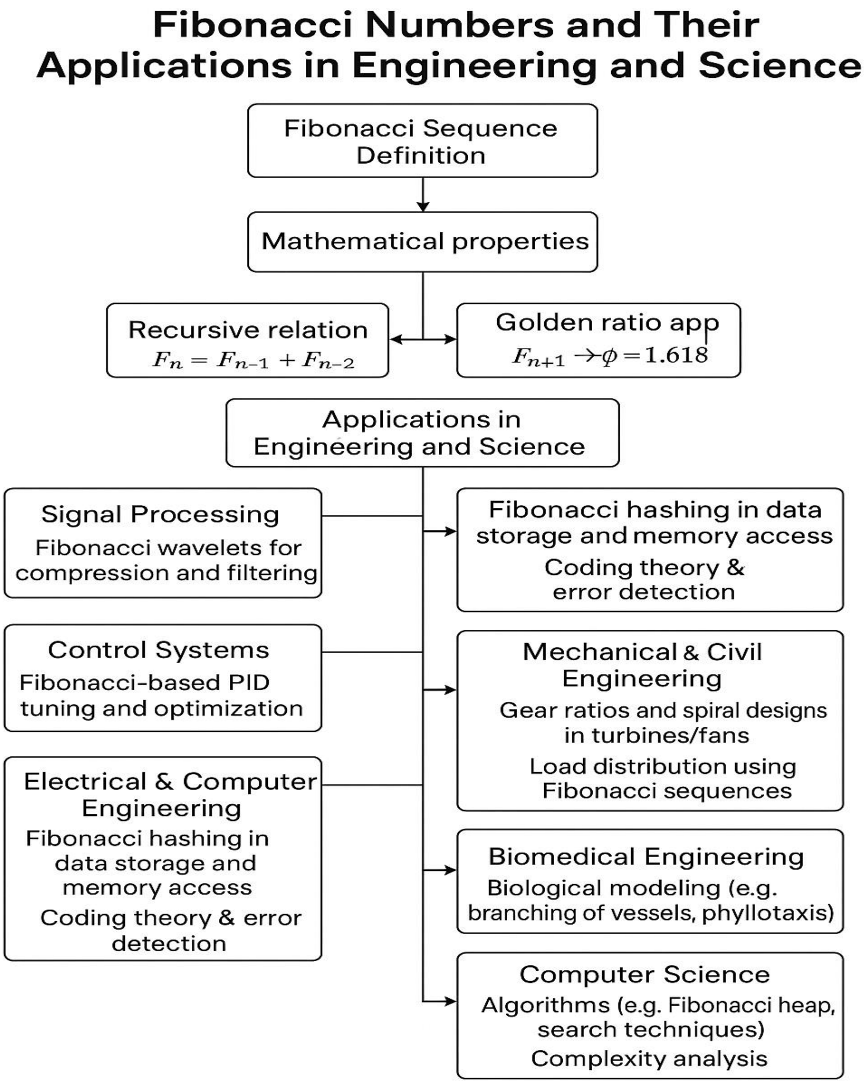
The Fibonacci sequence is equal to the sum of the two elements that came before it, according to mathematics. Fibonacci numbers, often represented by the symbol F_n, are numbers that belong to the Fibonacci sequence. Many authors start the sequence with 0 and 1, although some (like Fibonacci) start it with 1 and 1, while others start it with 1 and 2. The sequence starts with the numbers 0 and 1.

0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144…

As early as 200 BC, Pingala wrote a treatise describing the Fibonacci numbers in Indian mathematics. It listed potential patterns in Sanskrit poetry composed of syllables of two lengths. They have the name of Leonardo of Pisa, also called Fibonacci, an Italian mathematician who popularized the sequence in his work from 1202 and brought it to Western European mathematics Liber Abaci.

Unexpectedly, Fibonacci numbers are used in mathematics so frequently that a whole journal, the Fibonacci quarterly, is devoted to their study. Applications of Fibonacci numbers include graphs known as Fibonacci cubes that are used to connect distributed and parallel systems, as well as computer techniques like the Fibonacci heap storage structure and the Fibonacci search strategy. Although they are not seen in all species, they can also be seen in biological contexts including tree branching, pineapple fruit sprouts, artichoke blossoming, and the arrangement of bracts on a pine cone. Very closely associated with this sequence is the golden ratio, represented by the Greek letter φ (phi), which is roughly 1.618. As the Fibonacci sequence goes on, the ratio of consecutive numbers converges to this number. The golden ratio is generally thought to symbolize perfect balance and harmony and is thus commonly used in art, architecture. and design Both the Fibonacci series and the golden ratio illustrate a profound link between mathematics and nature, and their uses reach back centuries, from ancient architecture to contemporary art.

Applications of Fibonacci Sequences in Engineering and Science



Applications in Nature and Biology

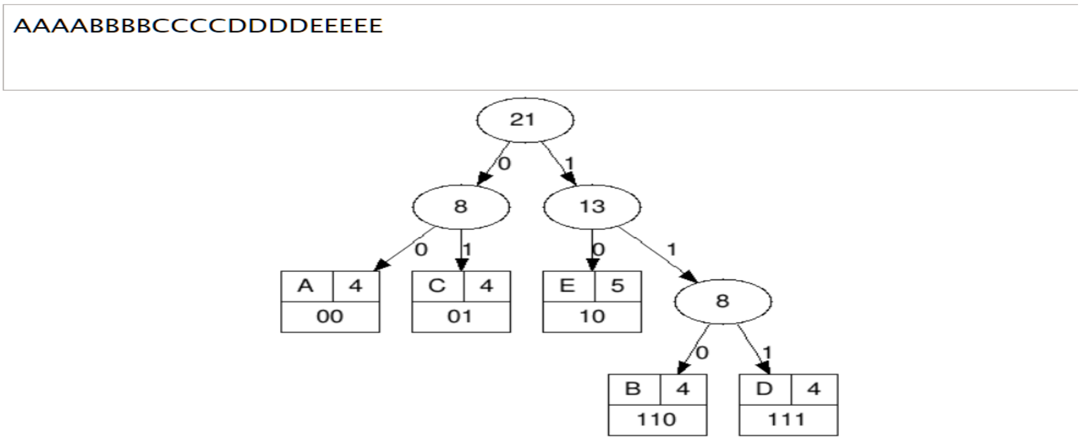
In plants, they occur in phyllotaxis the arrangement of the leaf, petal, and seed to optimize exposure to the sun and space utilization. The arrangement optimizes growth and reproduction. In animal husbandry, the Fibonacci sequence occurs in idealized population growth, e.g., in the traditional rabbit breeding problem. Moreover, many natural spiral structures. e.g., those of shells, pinecones, and sunflowers have spiral numbers equal to a Fibonacci number. These trends reveal how nature responds to mathematical concepts, employing the Fibonacci sequence to construct effective, symmetrical, and aesthetically pleasing shapes in animals and plants.






Application in Computer Science

In computer science, Fibonacci is significant to data structures and algorithms. It usually appears in recursive algorithms, where each call depends upon the results of previous calls, and in dynamic programming problems that are optimizing for performance by storing partial results. An example is the Fibonacci search algorithm, used to search sorted arrays. Apart from this, Fibonacci heaps, being a priority queue data structure, also utilize the sequence to achieve highly efficient amortized time for deletion and insertion. These uses illustrate how algorithm building and computational speedup are heightened by the mathematical properties of the Fibonacci numbers.



Suppose we start with n=**143.** The first **f** will be **89**. We mark it as used:

Fibonaccis	1	2	3	5	8	13	21	34	55	**89**	144
Usage bit	0	0	0	0	0	0	0	0	0	**1**	-

Now **n** = 143 - 89 = **54**. Fibonacci in hand is 55 which is > than 54. We mark it unused:

Fibonaccis	1	2	3	5	8	13	21	34	**55**	89	144
Usage bit	0	0	0	0	0	0	0	0	**0**	1	-

n = 54. f = 34. We mark it as used:

Fibonaccis	1	2	3	5	8	13	21	**34**	55	89	144
Usage bit	0	0	0	0	0	0	0	**1**	0	1	-

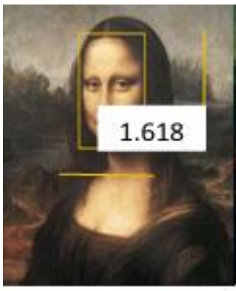
And finally to n = **0:**

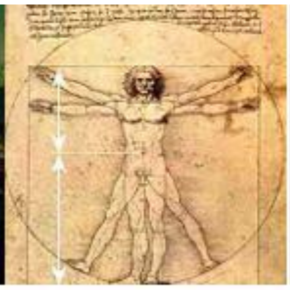
Fibonaccis	1	2	3	5	8	13	21	34	55	89	144
Usage bit	0	1	0	1	0	1	0	1	0	1	-

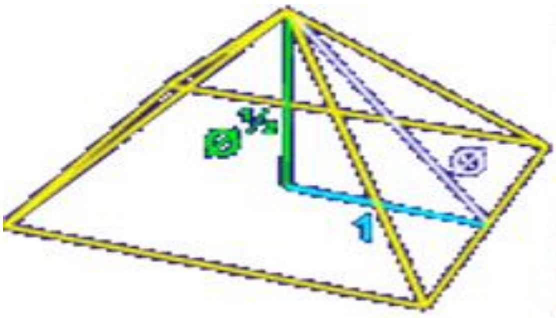
For the codeword, read the second row of above table from left to right: 0101010101
Append additional '1' bit: 0101010101**1**
Final codeword for 143 = 01010101011

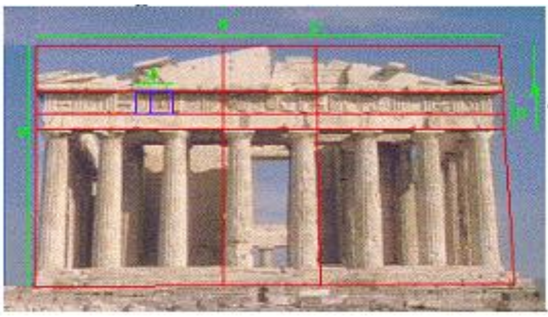
Application in Art and Architecture

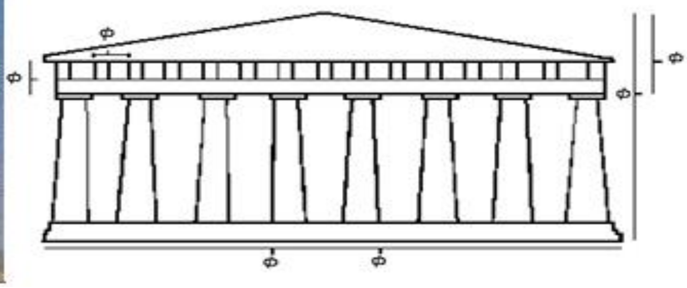
The golden ratio and Fibonacci sequence, around 1.618, have been valued in art and architecture for millennia for their properties of creating pleasing and well-proportioned designs by default. The Fibonacci sequence, a sequence where the sum of two previous numbers is precisely the following number, occurs frequently in measurement and spacing in design. Golden ratio, with which the series has a close association, is used to find ideal proportions. that are seen by the human eye as beautiful through time, these mathematical concepts have also surfaced in the paintings and buildings of well-known artists and architects. For instance, Leonardo da Vinci used the application of the golden ratio while designing his work, such as The Last Supper and Vitruvian Man, based on what he understood of harmony between nature and mathematics. Likewise, ancient buildings such as the Parthenon building in Athens exhibit proportions based on the golden ratio, and that is why they continue to appear well over a long period of time











Conclusion:

The Fibonacci sequence reveals deep patterns in nature, art and technology through its link to the golden ratio and recursion. Its wide-ranging applications highlights the beauty and order in both mathematics and the natural world.

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INTERNET OF THINGS (IOT) IN PRECISION AGRICULTURE

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Abstract:

Although only a few nations have implemented precision agriculture, India's agricultural sector still requires modernization through improved technology participation for enhanced production, distribution, and cost management. Internet of Things (IoT) sensors can provide valuable information about agricultural areas and enable actions based on user input. The development of IoT has given rise to the concept of machine-to-machine technology, allowing two machines to communicate with one another. Data that was previously stored on private servers can now be accessed remotely via the internet. Almost all businesses can benefit from the use of IoT, particularly those where connection speed is not a concern. To meet the growing demand for food, challenges such as harsh weather and accelerating climate change must be addressed. With the help of IoT technology, growers and farmers will be able to increase production and minimize waste across various areas, from optimizing fertilizer usage to reducing the number of trips made by farm vehicles.

Keywords: Internet of Things; Machine-To-Machine Technology; Precision Agriculture; IoT Sensors

Introduction:

Smart farming is a farming management concept aimed at enhancing both the quantity and quality of agricultural products. Today's farmers have access to advanced technologies such as GPS, soil scanning, data management, and the Internet of Things (IoT). The purpose of smart agriculture research is to establish a solid foundation for a farm management decision-support system. Smart agriculture addresses challenges such as population growth, climate change, and labor shortages. It encompasses various aspects of farming, from planting and watering crops to monitoring crop health and harvesting.

The Internet of Things (IoT) refers to a technology and environment that enables communication and real-time data exchange using sensors attached to various objects via the internet [1]. Various industries can leverage IoT for big data analytics, cloud computing, and more [2]. Traditionally, sending and receiving information from internet-connected devices required human intervention. However, IoT allows items to communicate with each other through Bluetooth, near-field communication (NFC), sensor data, and networks without the need for human involvement [3]. The IoT is a modern mechanism that has supplanted networked cloud applications and encompasses mechanical, electrical, and digital devices, as well as individuals with unique identifiers.

In IoT-based smart agriculture, a system is created to monitor agricultural fields using sensors (light, humidity, temperature, soil moisture, etc.) and automate irrigation systems. A significant advantage of IoT is its ability to transfer data without human transmission interfaces. Wireless Sensor Nodes (WSN) provide an ideal solution for addressing the challenges of monitoring large agricultural areas. Although actuator modules consume significant amounts of electricity, they are fewer in number and can be connected to a Personal Area Network (PAN). By utilizing existing Local Area Network (LAN) and internet infrastructure, this comprehensive framework can be integrated into an IoT-based system.

Most developed countries are advancing in agricultural digitization. In Japan, practices such as crop breeding, pest management, agricultural management, and the creation of meteorological data are widespread. Farmers in the United States have access to government databases for agriculture, research institutions, and libraries, as well as extensive data cloud systems. These databases enable farmers to stay informed about current market prices, crop development, and emerging skills and technologies in the agricultural sector. By utilizing computers, farmers can make informed decisions regarding the best crops to plant, optimal growing seasons, and effective farming methods. Similar systems are available for various agricultural management specializations from well-known financial management information system (FMIS) providers, including Wisu 10 and Agrineuvos.

The Food and Agriculture Organization (FAO) of the United Nations estimates that by 2050, the global population will increase by an additional 10 billion people, necessitating a rise in agricultural production. Many scientists are conducting research to enhance agricultural output to address these challenges [4,5]. The agriculture sector has been able to boost productivity and distribute resources more effectively due to innovative thinking and technological advancements, such as sensor systems and wireless sensor networks [6]. IoT significantly benefits innovative smart farming [7]. Agricultural automation enabled by IoT enhances agricultural output [8,9]. Additionally, IoT contributes to reducing waste, optimizing processes, and improving overall efficiency in agricultural practices.

To build a secure food supply chain, the Internet of Things (IoT) can be leveraged to significantly enhance agricultural productivity and efficiency [10]. IoT technologies can be applied across various domains of agriculture, including farm management [11], farm monitoring [12], livestock monitoring [13], irrigation control [14], greenhouse environmental control [15], autonomous agricultural machinery [16], and drone operations [17]. These applications contribute to the development of smart farming systems by enabling real-time data collection and responsive decision-making.

In particular, IoT empowers farmers to collect and utilize critical data to generate yield maps, facilitating precision agriculture practices that result in cost-effective and higher-quality crop production [18]. As illustrated in Fig. 1, the IoT-based agricultural process involves collecting data from farm equipment, crops, and livestock; building a centralized database; analysing the information to derive actionable insights; and delivering tailored recommendations to farmers via text messages. This systematic integration of IoT technologies helps streamline operations, optimize resource usage, and support sustainable agricultural development.

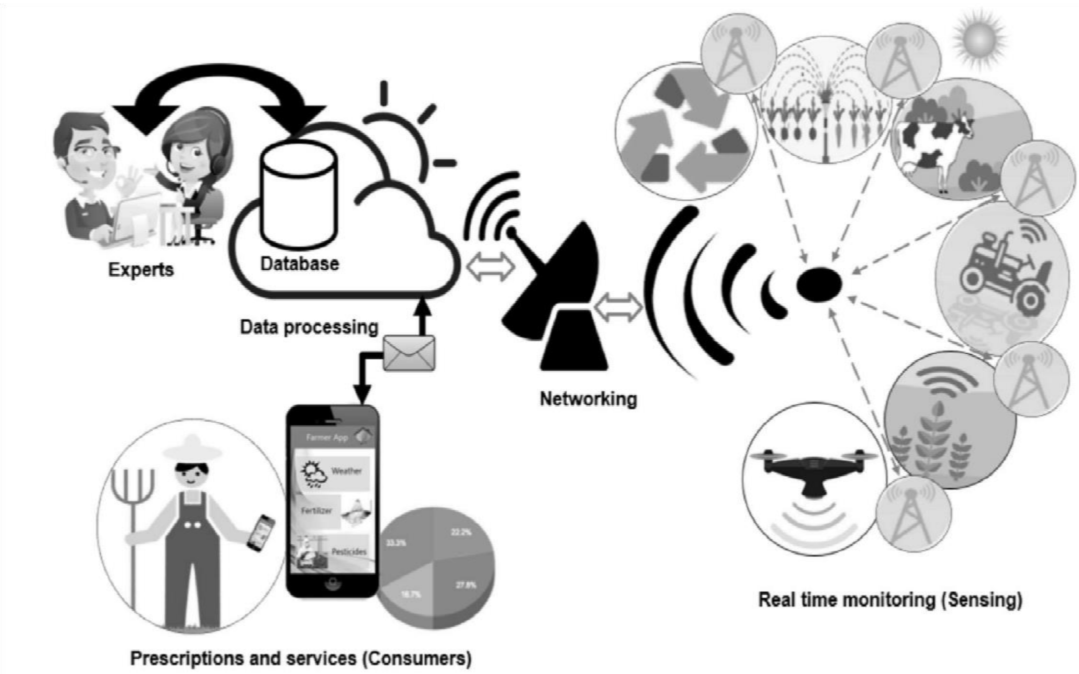

Fig. 1: IoT procedures in agriculture

Applications of the Internet of Things in Agriculture

1. Management System: Recent advancements in wireless sensor networks have made it easier to measure a variety of data types [20]. These developments have enabled the

Internet of Things (IoT) to address numerous agricultural challenges and facilitate efficient and sustainable farming practices [21]. As illustrated in Fig. 2, IoT applications in agriculture can be broadly categorized into the following four groups:

(a) Management System: This category encompasses systems that assist farmers in making informed decisions regarding resource allocation, crop selection, and overall farm management. By integrating data from various sources, these systems can optimize agricultural practices and improve productivity.

(b) Monitoring System: Monitoring systems utilize IoT sensors to continuously track environmental conditions, soil moisture levels, crop health, and other critical parameters. This real-time data allows farmers to respond promptly to changing conditions, ensuring optimal growth and reducing resource waste.

(c) Control System: Control systems leverage IoT technology to automate various agricultural processes, such as irrigation, fertilization, and pest management. By automating these tasks, farmers can enhance efficiency, reduce labor costs, and minimize the environmental impact of their operations.

(d) Unmanned Machinery: This category includes the use of drones, autonomous tractors, and other unmanned vehicles equipped with IoT technology. These machines can perform tasks such as planting, monitoring, and harvesting crops, thereby increasing efficiency and reducing the need for manual labor [22; 23].

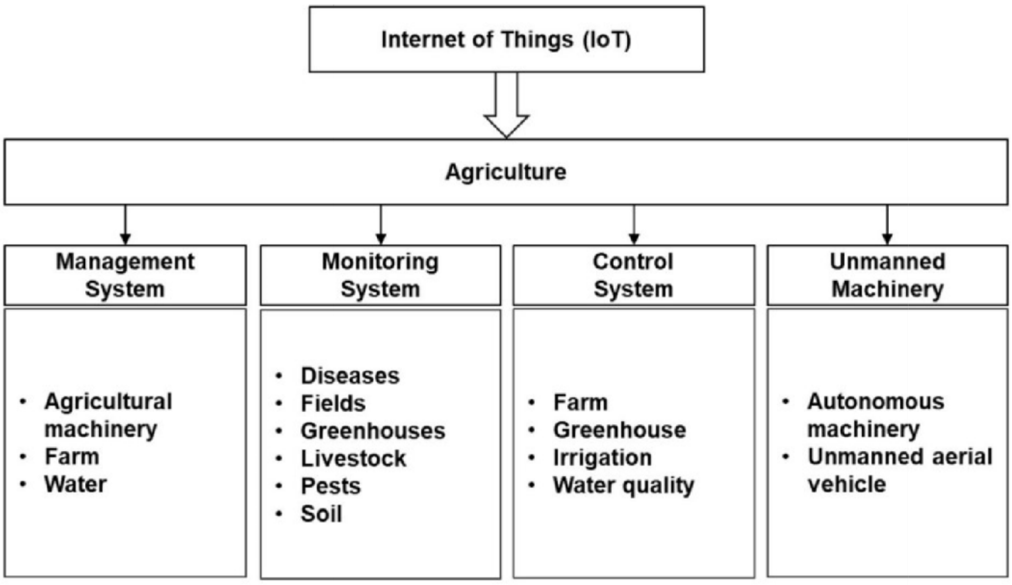

Fig. 2: IoT application in agriculture, comprising of management system, monitoring system, control system, and unmanned machinery

- **Agricultural Machinery**: IoT technology is increasingly utilized in conventional agricultural production to provide essential information regarding the management of agricultural machinery operations in real-time. This includes recognizing the requirements for machinery operation and control [24]. These systems enable remote monitoring of field environments and the operating conditions of agricultural machinery, ultimately enhancing agricultural production.
- **Farm Management**: To assist farmers in making informed decisions, IoT-based farm management information systems (FMISs) have been developed [25, 11]. These systems manage all data collected from fixed farm sensors. By employing big data analysis, FMISs deliver financial analysis reports to farmers, along with data related to farm inputs such as machinery, seeds, pesticides, and fertilizers. Additionally, a precision agriculture management system (PAMS) was proposed using IoT and WebGIS [26]. PAMS is designed for managing large agricultural production farms and provides features such as data collection, retrieval, analysis, production monitoring, remote operation of production processes, and support for production decisions. This system leverages advanced technologies like IoT and WebGIS to enhance farm management.
- **Water Management**: The Multi-Intelligent Control System (MICS) was established to address the growing challenges of water shortages in the agricultural sector [27]. This IoT-based system is designed to manage all water resources by monitoring and regulating water usage and reservoir water levels. The MICS has effectively addressed water management in agriculture, demonstrating the capability to save up to 60% of water resources.

2. Monitoring System

- **Diseases**: An IoT-based cognitive monitoring system for early plant disease forecasting has been developed [28]. This system not only provides environmental monitoring data to maintain optimal conditions for crop cultivation but also forecasts conditions that could lead to disease outbreaks using environmental sensor data. Equipped with artificial intelligence and predictive algorithms, the system mimics the decision-making capabilities of human experts and sends warning messages to users. Additionally, a multicontext fusion network (MCFN)-based automated system for agricultural IoT was proposed [29] to identify crop diseases in real-time. This system utilizes deep learning and MCFN technology to simulate actual crop conditions, enhancing disease detection capabilities.

- **Field Monitoring**: Field monitoring is essential in agriculture for controlling crop-growing conditions and improving crop quality and yield. IoT applications often utilize low-cost sensors and networks for field monitoring. An intelligent system for monitoring agricultural fields that measures soil temperature and humidity has been presented [30]. The data collected through this method is stored in the cloud for future analysis, which can inform field management decisions. A framework that includes a monitoring module and a knowledge management (KM) basis has been suggested to enhance agricultural automation and field monitoring [31]. This approach has led to more efficient water resource usage and reduced labor costs.
- **Greenhouse Management**: Environmental factors such as temperature and humidity significantly impact plant quality and production in greenhouses. Continuous monitoring of these factors allows farmers to maximize crop yield. Traditional methods for monitoring greenhouse conditions often lack resolution, require extensive labor, and are time-consuming. To address these issues, an IoT-based system was proposed to track environmental parameters in an orchid greenhouse and monitor the growth conditions of Phalaenopsis orchids [15]. This system combines a wireless imaging platform with an environmental monitoring system to measure conditions in real-time.
- **Livestock Monitoring**: Monitoring systems have been implemented in agriculture to collect data on various animal species, including cows [32] and poultry [33]. For instance, the Moocall system uses motion sensors to track the movements of pregnant cows [32]. This system notifies farmers via SMS two hours before a cow gives birth, helping to reduce calf mortality rates. Moocall claims an accuracy rate of over 95%, with a 7% reduction in mortality at calving. Precision livestock farming (PLF) is a comprehensive management framework that includes monitoring, data analysis, decision-making, control, and intervention for diverse livestock [34]. PLF systems enhance decision-making by reducing the need for manual observations and can automate various operations, significantly decreasing the time and effort required for animal management.
- **Pest Management**: An autonomous early warning system was proposed [35] to prevent the recurrence of pests, such as the large Oriental fruit fly (Bactrocera

dorsalis). This system aims to reduce the overuse of chemical pesticides by farmers. It consists of three key components: wireless monitoring nodes (WMN), a remote-sensing information gateway (RSIG), and a host control platform (HCP), utilizing wireless communication protocols like ZigBee and GSM. The proposed system includes a real-time alert mechanism that notifies system administrators and government authorities via GSM when critical events are imminent, thereby safeguarding farms and ensuring food supply security.

- **Soil Monitoring**: Maintaining a healthy soil environment is crucial for crop development. An IoT-centered intelligent soil observation system has been created to monitor soil conditions [37]. This system employs various sensors, including pH, temperature, and humidity sensors, to gather data on the soil environment, which is then relayed to users via mobile applications. This information aids in making informed decisions regarding pesticide application and irrigation. Additionally, an IoT-centered fertilizer system has been introduced to monitor soil nutrients, analyze the required amount of fertilizer, and manage subsequent fertilizer applications through a control system.

3. Control System

- IoT is utilized in agricultural systems to regulate resources such as irrigation, water quality, and the environmental conditions of farms and greenhouses [37]. Control systems in agriculture are particularly important for maintaining optimal growth environments, ensuring high-quality produce.
- **Farm Control Systems**: An agricultural production control system utilizing IoT technology has been developed [38]. This control system operates on the farm to manage actuators and collect data using autonomous sensing devices. Light-dependent resistors (LDRs) and light-emitting diodes (LEDs) are integrated into IoT-centered systems using NPK sensors [39]. By monitoring and analyzing soil nutrients, the system guides farmers on the appropriate amount of fertilizer needed at regular intervals.
- **Greenhouse Control**: Environmental variables in an IoT-based greenhouse have been monitored, focusing on temperature and relative humidity to optimize growth rates [15]. A control system was designed to maintain ideal temperature and humidity levels within the greenhouse. A wireless sensor node was developed to facilitate effective communication between the sensor and the controller, adhering

to communication interface standards [40]. Data transmission speed was analyzed, showing a 100% data rate up to a distance of 25 meters between the wireless sensor node and the controller, which communicate wirelessly via Bluetooth.

- **Irrigation Management**: Precision agriculture employs IoT-based irrigation systems to optimize water usage [41]. An autonomous sprinkler system was developed to maintain specific water levels based on real-time soil moisture data [42]. This system regulates the sprinkler operation according to the moisture content of the soil, functioning without user intervention. Additionally, IoT features enable remote operation of sprinklers based on weather forecasts, preventing water waste and reducing plant mortality.
- **Water Quality Management**: Smart systems based on IoT have been created to manage water quality for agricultural uses, particularly in the treatment of urban wastewater [43]. These systems monitor pH levels to ensure water quality remains within acceptable limits, allowing for the recycling and reuse of municipal wastewater in agriculture.

4. Unmanned Machinery

Autonomous Machinery: Recent advancements in wireless communication technology have enabled the integration of IoT in agricultural machinery, leading to the development of fully autonomous tractors. Various agricultural devices can be interconnected to communicate and share data. For instance, multiple tractors can connect and interact with one another to replicate the steering angle and speed of a primary tractor for synchronized operation [31]. Machine Sync systems facilitate direct communication between tractors, combines, and other systems, enhancing the efficiency and precision of crop harvesting.

Equipment such as AutoTrac Vision allows machinery to follow real crop rows, minimizing crop damage and increasing productivity. To prevent crop damage and ensure complete coverage for fertilizer application and other tasks, AutoTrac RowSense technology is employed.

Unmanned Aerial Vehicles (UAVs): Precision agriculture has evolved beyond traditional practices through the use of IoT-based unmanned aerial vehicles (UAVs) [17]. The adoption of UAVs in agriculture is expected to grow steadily, as they can perform a variety of tasks, including irrigation, fertilization, insecticide application, weed management, plant growth monitoring, disease control, and field-level phenotyping [44]. UAVs equipped with spectral cameras are widely used for environmental monitoring of farmland and analyzing pest and disease outbreaks based on aerial imagery [45]. Additionally, thermal or heat-seeking cameras mounted on UAVs can monitor plant thermal characteristics, detect wildlife near farms, and observe crop health and water shortages [46].

Limitations:

While IoT has the potential to transform agriculture and provide significant benefits to farmers and the agricultural industry, it also faces several limitations:

- Cost: Implementing IoT can be expensive, particularly for marginal and small farmers who may lack the financial resources to invest in the necessary infrastructure and technology.
- Connectivity: Many rural areas, where agriculture is prevalent, suffer from poor internet connectivity. IoT devices require a stable and reliable internet connection to function optimally, and a lack of connectivity can hinder their effectiveness.
- Power Supply: IoT devices need a constant power source to operate. In rural areas with limited access to electricity, maintaining reliable power for these devices can be challenging.
- Data Privacy and Security: IoT devices collect and transmit vast amounts of data, including sensitive information about agricultural operations, livestock, and crops. Protecting the security and confidentiality of this data is crucial, as any compromise could have serious repercussions for farmers and the agricultural sector.
- Technical Knowledge and Skills: Effective use of IoT in agriculture requires technical expertise. For some farmers, the need for training to learn how to use and manage IoT devices may pose a barrier.
- Maintenance and Support: Timely maintenance and upgrades are essential for the proper functioning of IoT devices. Breakdowns or malfunctions can disrupt agricultural operations if not adequately supported and maintained.
- Weather Factors: Agricultural environments are often exposed to challenging weather conditions, such as high temperatures, humidity, and dust. These factors can impact the performance and longevity of IoT devices.

Conclusion:

In summary, IoT in agriculture has the potential to enhance monitoring and sensing of production, including the use of farm resources, animal behavior, crop development, and food processing. Furthermore, IoT provides insights into specific farm issues, such as how environmental conditions and weather influence the development of weeds, pests, and diseases. Recently, IoT has been extensively applied across various agricultural technology domains. By selecting appropriate sensors and networks based on factors such as sensor range, power consumption, and cost, while considering the IoT operating environment, farmers can achieve high efficiency and low costs in agricultural production.

Ensuring a reliable network and data security is essential, and IoT devices should be protected when used in harsh outdoor agricultural conditions. IoT is expected to address many current challenges in agriculture, leading to improved quality and production. Additionally, IoT has the potential to increase agricultural revenue by reducing labor and material costs.

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INTERDISCIPLINARY PERSPECTIVES ON THE SOCIETAL IMPACTS AND POLICY TRENDS OF SCIENCE AND TECHNOLOGY

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Abstract:

The social impacts of scientific and technological advances – whether desirable or undesirable – have been one of the primary foci of contemporary policy research, much of which employs distinct interdisciplinary approaches. In this paper, we seek to characterize the topical, methodological, theoretical, and geographical trends of recent science and technology policy studies, while paying particular attention to capturing any systemic patterns of trends. Technology is an invention created using science, which needs to be sustained by prudent management and law. The research goal is to narrow down a middle ground where all these independent fields can meet and share a symbiotic relationship without stifling each other. We conclude with a discussion of the various ramifications of our findings for future research directions and, in the process, highlight issues including technological innovation and diffusion, science and technology for sustainable energy development, evidence-based decision-making, and information technology and cyber security.

Keywords: Science and Technology Policy; Evidence-Based Decision-Making; Technological Innovation and Diffusion; Information Technology and Cyber Security; Advancement, Law, Technology for Sustainable Energy Development.

Introduction:

Impacts of scientific and technological advances – whether desirable or undesirable – have been one of the primary foci of contemporary policy research. Economic and socio-political implications of science and technology development associated with global climate change and sustainable energy generation, big data and information and communication infrastructure and network, food security and bioengineering, and nano-scale research and applications, to name a few, have been frequently discussed by scholars, practitioners, the media, and ordinary citizens, and the related government policies have naturally been reflective of such discussion. Acknowledging the importance of this topic domain, in this paper, we attempt to characterize the recent trends of science and technology policy studies and provide some direction for future research. Relate to how science and technology are characterized generally. These three major topical foci explore science and technology as (a) innovative, (b) risky, or (c) integral to the policy process. The focus of contemporary policy scholarship in science and technology policy is divided between investigating innovation processes and an exploration of factors that function as barriers to the adoption of new information and technology. Today, while it is the local and international companies, laboratories and public research institutions that study science and create technology (Albert and Laberge, 2007), its development and evolution largely still depend on economics, law, politics and culture (Weiss, 2005). Although law and science have achieved unprecedented hegemony, both recognised and claimed to be limited by their own fields of action. In science, the limits are co-extensive with the scientific method of inquiry; while in law, the limits reside in procedural technicalities (Silbey, 2008). Another issue is that law and science have long been represented as two fundamentally different enterprises, which gives rise to two stark realities: on the one hand, there will always be an unavoidable culture clash between the practitioners of law and science respectively and on the other hand, law will continually imbibe the culture of science, while adjudicating upon scientific issues (Jasanoff, 1995).

Innovation through Science and Technology

Advances in scientific understanding and the development of new technologies are considered fundamental to maintain competitive market advantages and continued economic growth and, in this context, are considered beneficial to society. Broadly speaking, government policies in this realm are concerned about promoting the development, production, and diffusion of innovative Science and technology to achieve such ends. The majority of innovation research seeks model innovation processes, explore the mechanisms of innovation, and identify the conditions that facilitate it. Within the last three years, researchers have increasingly applied a multi scalar lens to understand the diffusion of policies and knowledge assumed necessary to foster innovation. Subtopics within this area of research also focus on society's evaluation and adoption of new technologies and their overall impacts.

Mechanism of Innovation:

An examination of the mechanisms of innovation relies on theoretical lenses to create comprehensive model of the innovation process. Most innovation process models conceptualize the process as linear, proposing remarkable and distinct stages that enable a deeper exploration of the causal mechanisms underlying the process or lifecycle, The early stages in the innovation lifecycle involve the transfer of knowledge and technology and analytical frameworks used to explore this stage often focus on the systemic transfer of scientific knowledge and technology between universities, industries, and government institutions, also referred to as the triple helix. Recent science and technology policy studies focus specific attention on diffusion processes that result in the transfer of knowledge and technology.

Impact of Science and Technology on Society:

The term "technology" refers to the actual application of scientific knowledge, as well as the apparatus and instruments that follow. We are in the midst of an era of fast transition, in which technological advancements are revolutionizing the way we live while also propelling us farther into the abyss of disaster, as seen by climate change and resource scarcity.

1. **Positive impact of technology on society:**

   Technology's development and use have helped societies in increasing productivity, expanding service accessibility, and improving overall well-being. Where have technological developments aided the most?

   Healthcare and wellness advancements:

   Technology has the potential to significantly improve health and healthcare systems as we know them. From AI-powered clinical drug trials to enabling preventative patient monitoring to wellness solutions such as wearables, the possibilities are endless. We've seen technology fill gaps in healthcare during the pandemic. Telemedicine apps are the first step toward making healthcare more equitable and accessible to all people, regardless of socioeconomic status. The widespread adoption of technology by both patients and healthcare professionals has enormous potential to improve the efficiency of public health entities. Advances in preventative health technology (such as wearable) can reduce overall healthcare costs by monitoring patients status and detecting abnormalities earlier, allowing for faster response. Complex healthcare systems powered by AI analytics can more effectively distribute care and treatment. Virtual Reality Therapy is being tested on patients who have experienced severe trauma, as facing your fears again and surviving proved to be. the biggest therapy leap for many.

Education:

Artificial intelligence can help students with disabilities determine the best way for them to learn efficiently and with tangible progress. Automation and systemization can solve the ultimate pain point for teachers across the globe: administrative tasks, which take a lot of their time.

2. Negative impact of science and technology on society:

The negative impact of technology on society involves mass-produced products, with social media being the most frequently blamed. A plethora of research has been conducted on the subject, with social media being ranked as the number one source of misinformation, hate speech, and harassment on the one hand, and a source of isolation and depression on the other.

Fake news & misinformation:

Fake news and misinformation have been with us for quite some time, but with the tech advancements moving rapidly, people find it hard to keep up with what's true and what not. Social media platforms in general are struggling with content moderation. At the beginning of 2021, Twitter launched a pilot 'Birdwatch' Programme, aiming to build a community to help fight misinformation and fake news.

Technology affects our sleeping habits:

Technology has undoubtedly influenced how we sleep. Many of us stay up far too late texting friends or scrolling through social media. Sometimes we're tired, it's difficult to put the devices away. How many of us have a habit of waking up in the middle of the night to check our phones? Both children and adults spend countless hours watching funny cat videos or other mindless entertainment. It's difficult to break free from apps that are purposefully designed to keep us hooked. Late night device use alters our brain's production of melatonin, the sleep hormone, making it more difficult to get a good night's sleep.

Technology promotes a more sedentary lifestyle. This could be one of the most significant disadvantages of living in a device-filled world. Children who play video games or spend a lot of time online do not get as much physical exercise as those who do not. Technological advancements keep us glued to our devices, whether we're on the couch watching TV or holding a cell phone. What begins as a quick scroll through social media quickly becomes a spiral down the rabbit hole with no end in sight.

The more time we spend on YouTube and Instagram, the less time we spend doing other things outside. Technology leads to neck pain and bad posture. When you're slumped over your phone, it's difficult to sit up straight. As a result of not sitting up straight, many of us experience back and neck pain. We also do not hold our phones at eye level when looking at them. Instead, we lean over with our heads down to inspect it. All of this contributes to poor posture, neck and back pain, and occasional wrist pain as a result of our constant use of our devices.

Perception Risk:

Studies of risk perception examine the judgments people make when they are asked to characterize and evaluate hazardous activities and technologies. This research aims to aid risk analysis and policy-making by (i) providing a basis for understanding and anticipating public responses to hazards and (ii) improving the communication of risk information among lay people, technical experts, and decision-makers. This work assumes that those who promote and regulate health and safety need to understand how people think about and respond to risk. Without such understanding, well-intended policies may be ineffective.

Science and Technology in the Policy Process:

Science and technology play an integral role in the development, communication, and understanding of various policy issues. Science and Technology Policy (STP) refers to the guidelines and frameworks that govern research and development priorities, methods, ethics, and applications in scientific and technological fields. In the United States, STP plays a crucial role in shaping economic growth, national security, and societal well-being. It facilitates the interaction between various sectors, including government agencies, private firms, and academic institutions, ensuring that scientific advancements translate into tangible benefits for society. The historical context reveals a strong government investment in science and technology, particularly during the Cold War, driven by defense needs and national prestige.

Today, the U.S. government actively supports innovations in fields such as nanotechnology and networking and information technology through coordinated programs involving multiple agencies. The Office of Science and Technology Policy and the National Science and Technology Council oversee these initiatives, reflecting a commitment to interagency collaboration. As STP evolves, it faces challenges related to financing, governance, and the ethical implications of public-private partnerships in research, prompting ongoing discussions about the optimal role of government in fostering innovation while addressing public interests and private sector needs.

Information Technology

The integration of learning and Information Technology (IT) currently has a good impact on education. Besides making it easy, IT also provides opportunities to achieve learning goals anytime and anywhere. Many studies have discussed how to achieve successful learning through IT. IT here only serves as a support for learning, not as a science. This research develops a model or instrument used to achieve learning success by placing IT as a science. As a result, a learning model was successfully developed by combining several perspectives related to IT; students (Background, desire, and skill), teacher (teaching), and institution (infrastructure).

Cyber Security:

Cyber security is a rapidly growing area of computer science and technology, encompassing software, systems, IT, networks, communications, cryptography, and various other fields across numerous platforms including traditional computers, smart phones, tablets, servers and any networkable device, whether Internet-connected or not.

Silent Characteristics trends in contemporary Science and Technology

- Increasing Scale
- International character
- Rationalization
- Symbiotic Interdependence

Conclusion:

Our review of recent policy literature reveals three primary themes characterizing science and technology policy research as (a) innovative, (b) risky, or (c) integral to the policy process Notable themes emerged in our review and we highlight those, touching on associated topical methodological, theoretical, and geographical trends. More specifically, our review found that a substantive amount of recent science and technology policy research focused on innovation and diffusion, science and technology for sustainable development, evidence-based decision making, and information technology and cyber security.

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ICT LITERACY AMONG LIBRARY PROFESSIONALS FOR ENHANCED LIBRARY SERVICES IN THE DIGITAL AGE

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Abstract:

In the rapidly evolving landscape of information and communication technology (ICT), libraries are transitioning from traditional repositories of printed materials into dynamic, technology-driven information centres. This transformation demands that library professionals possess strong ICT literacy, encompassing skills in library automation, digital cataloguing, resource sharing, and e-service delivery. ICT has revolutionized core library operations, including circulation, acquisition, cataloguing, serials management, and membership services, enhancing efficiency and user satisfaction. This study investigates the current state of ICT literacy among library professionals and its impact on service quality and digital transformation. The findings aim to guide the creation of effective training programs and strategic policies that promote ICT integration, ensuring libraries remain relevant and accessible in the digital era.

Keyword: Information and Communication Technology, ICT, ICT Literacy, Library Services

Introduction:

In the rapidly evolving landscape of information and communication technology (ICT), libraries are undergoing significant transformation from traditional repositories of printed materials to dynamic, technology-driven information centers. The digital environment has redefined how information is stored, accessed, and disseminated, placing new demands on library professionals to adapt and evolve. In this context, ICT literacy among library professionals has emerged as a critical competency that directly influences the quality, efficiency, and relevance of library services.

ICT literacy refers to the ability to effectively use digital tools, systems, and platforms for accessing, managing, and communicating information. For library professionals, this encompasses skills in using library automation systems, digital cataloguing, e-resources management, online reference services, and digital preservation techniques. As users increasingly rely on digital access and remote services, libraries must not only upgrade their technological infrastructure but also ensure that their personnel are equipped with the necessary ICT skills to support users in a digital environment.

Despite the growing recognition of ICT's role in library operations, many libraries, especially in developing regions, continue to face challenges in achieving a fully ICT-literate workforce. These challenges include limited training opportunities, lack of institutional support, budget constraints, and resistance to change. Addressing these barriers is essential to improving service delivery, ensuring access to digital resources, and maintaining the library's role as a central hub for knowledge and learning in the information society.

This study aims to explore the current level of ICT literacy among library professionals and examine how these competencies impact the improvement of library services in the digital age. By identifying skill gaps and institutional needs, the research seeks to provide actionable insights for developing effective training programs and strategic policies that foster digital transformation in libraries.

ICT Applications can be used in the Library:

- **ICT used in Circulation:** ICT streamlines the circulation process—checking books in and out, renewing items, and managing overdue fines. Integrated Library Management Systems (ILMS) such as KOHA, LIBSYS, or SOUL automate these tasks, enabling faster, more accurate service. Barcode scanners or RFID systems speed up transactions, and automated alerts via SMS or email inform users of due dates and fines, improving the user experience.
- **ICT used in Acquisition:** Acquisition involves selecting, ordering, and purchasing library materials. ICT tools simplify the workflow through online vendor databases, digital order forms, and acquisition modules in ILMS. These systems track budgeting, generate reports, and maintain vendor communication electronically. They help ensure that purchasing decisions are timely, cost-effective, and aligned with users' needs.
- **ICT used in Cataloguing:** ICT has revolutionized cataloguing through Online Public Access Catalogues (OPAC) and Machine-Readable Cataloguing (MARC) formats. Library professionals can now use software like MARC21, Dublin Core, or AACR2/RDA standards to create and share metadata. Tools like OCLC WorldCat also facilitate cooperative cataloguing, allowing libraries to access and copy records, reducing duplication of effort.

- **ICT used in Resource Sharing:** ICT enables efficient inter-library loans (ILL), consortia-based access, and document delivery services. Libraries connected through digital networks can share resources such as e-books, journals, and databases. Platforms like DELNET, INFLIBNET, and Shodhganga in India offer access to shared resources, enhancing availability and reducing acquisition costs.
- **ICT used in Stock Verification:** ICT applications facilitate accurate and quick stock verification through automated tools. Barcode or RFID-based inventory management systems allow librarians to scan items, check for discrepancies, identify lost or misplaced materials, and generate reports. This minimizes human error, saves time, and ensures that the collection is up-to-date and accurately recorded.
- **ICT used in Membership:** Membership management is simplified through ICT-enabled registration systems that handle user data, issue library cards (smartcards or RFID-based), and maintain borrowing history. Online forms, biometric verification, and digital ID integration make the process seamless, secure, and accessible. Libraries can also categorize users and offer personalized services based on their profiles.
- **ICT used in Serial Management:** Serials (journals, magazines, newspapers) require regular tracking and updating. ICT tools in ILMS help manage subscriptions, renewals, check-ins, and claims for missing issues. E-journal platforms provide real-time access to current and archived issues. Automation ensures timely availability and reduces the manual workload in tracking frequency, volume, and publisher correspondence.
- **ICT used in Library Services:** ICT transforms traditional library services into dynamic, user-friendly offerings. Services such as:

a) Online Public Access Catalogues (OPAC) for book searching.
b) Digital reference services via email or chat.
c) Remote access to e-resources.
d) Multimedia content and e-learning tools.
e) Mobile apps and library portals enable users to interact with the library anytime, anywhere. ICT also supports information literacy programs, virtual tours, and personalized recommendations, enriching the user experience.

ICT Literacy for Library Professionals:

ICT literacy for library professionals refers to the essential skills and knowledge needed to effectively use digital technologies in managing library operations and services. It includes proficiency in using computers, library management systems, digital cataloguing tools, e-resources, and online databases. ICT-literate librarians can automate tasks like circulation, acquisition, and serial management, provide digital reference services, and support users in accessing and evaluating online information. In the digital age, ICT literacy is crucial for enhancing service quality, improving user satisfaction, and ensuring libraries remain relevant, accessible, and efficient information hubs.

Advantages of ICT Literacy for the Users:

1. Online information services like Ask Librarian and instant messaging have brought desired changes in Information Literacy.
2. Makes possible the use of resources and systems to access and assess information regardless of the medium's capacity.
3. Enable clients to search for information separately and pointedly, saving time.
4. Provides simple and quick access to the right information at the right time.
5. Allows users clear and fast communication to access and disburse information.
6. Improves user satisfaction.
7. Help and encourage the user to look for information sources now and then with greater self-dependency and certainty.

Advantages of ICT Literacy for Library Professionals:

1. Saves time, energy, effort, and cost for both users and library experts.
2. Minimised the wedge between the information searcher and the information provider.
3. Encourages libraries to be more confident while serving users with information.
4. Resource sharing has become easier.
5. Brings accuracy and reliability.
6. ICT allows multiple users access to electronic resources like e-books, e-magazines, and e-journals, etc. at the same time.
7. ICT applications allow users to transcend traditional libraries to dive deep into information with the aid of a virtual library, where the user can access information anytime and anywhere.
8. It offers the user correct data or information at the opportune time.

9. ICT application considerably reduces the maintenance, management, organization, and dissemination of information.

Conclusion:

The integration of ICT in libraries is essential for enhancing the quality and efficiency of services. Staff proficiency in ICT is crucial for managing resources, supporting users, and improving information accessibility. Automating processes like circulation and cataloguing significantly boosts performance and user satisfaction. However, libraries, particularly in developing regions, face challenges such as limited training, funding issues, and resistance to change, hindering full digital transformation. Addressing these challenges through targeted training and policy development is necessary for a future-ready library workforce. Ultimately, promoting ICT literacy in libraries is vital for ensuring sustainable and inclusive access to information.

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NANOTECHNOLOGY IN PHYSICS: MANIPULATING MATTER AT THE ATOMIC SCALE

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Abstract:

Nanotechnology enables precise control over matter at the atomic scale, allowing for the design and fabrication of novel materials and devices with unique properties. By manipulating individual atoms and molecules, researchers can create nanostructures with tailored electronic, optical, and magnetic properties. This paper explores recent advances in nanotechnology and their implications for physics, including the development of new materials, devices, and applications. We discuss the challenges and opportunities in this field, and highlight the potential for breakthroughs in areas such as quantum computing, energy storage, and sensing.

Keywords: Nanotechnology, Atomic Scale, Nanostructures, Quantum Physics, Materials Science.

Introduction:

Nanotechnology, a field that involves the manipulation and control of matter at the atomic and molecular scale, has revolutionized various scientific disciplines, including physics. The ability to manipulate matter at such a minute scale has opened up new avenues for research and applications, ranging from quantum computing to advanced materials science. This paper explores the fundamental principles of nanotechnology, its applications in physics, and the recent advancements in the field.

Fundamental Principles of Nanotechnology:

Nanotechnology is defined as the manipulation of matter with at least one dimension sized between 1 and 100 nanometres. At this scale, quantum mechanical effects become significant, leading to unique properties that differ from those at larger scales. The National Nanotechnology Initiative (NNI) in the United States describes nanotechnology as a field that encompasses science, engineering, and technology conducted at the nanoscale, enabling novel applications in various fields such as physics, chemistry, biology, and engineering.

Applications in Physics:

- **Quantum Computing:** One of the most promising applications of nanotechnology in physics is in the development of quantum computers. Quantum computing relies on the principles of quantum mechanics to perform computations. At the nanoscale, quantum bits (qubits) can be manipulated to perform complex calculations much faster than traditional computers. The ability to control and manipulate individual atoms and molecules is crucial for the development of stable and scalable qubits.
- **Material Science:** Nanotechnology has significantly impacted materials science by enabling the creation of new materials with unique properties. For instance, nanomaterials such as graphene, carbon nanotubes, and quantum dots exhibit exceptional mechanical, electrical, and optical properties. These materials have potential applications in various fields, including electronics, energy storage, and biomedical engineering.
- **Atomic-Scale Manipulation:** The development of tools such as the scanning tunnelling microscope (STM) and atomic force microscope (AFM) has allowed scientists to manipulate individual atoms and molecules. These tools enable the precise control of matter at the atomic scale, allowing for the fabrication of nanoscale structures and devices. This capability has been instrumental in the advancement of nanotechnology, leading to breakthroughs in various scientific fields.

Recent Advancements:

- **Synthesis and Characterization:** Recent advancements in nanotechnology have focused on the synthesis and characterization of nanomaterials. Various methods, such as chemical reduction, have been developed to produce nanoparticles with controlled morphology and properties. These methods allow for the precise manipulation of nanomaterials, making them suitable for specific applications. Additionally, advanced characterization techniques, such as electron microscopy and spectroscopy, provide insights into the structure and behaviour of nanomaterials at the atomic and molecular levels.
- **Integration and Automation:** The integration of atomic-scale manipulation with well-established lithographic processes has pushed the field of nanotechnology to new heights. Automation of atomic-scale manipulation has enabled the reproducible fabrication of large-scale arrays of quantum structures. This integration has vastly

extended the capability of in situ characterization, allowing for the examination of charge and spin transport behaviours from mesoscopic to atomic length scales.

Conclusion:

Nanotechnology has fundamentally transformed the field of physics by enabling the manipulation of matter at the atomic and molecular scale. The unique properties exhibited by nanomaterials have led to significant advancements in quantum computing, materials science, and atomic-scale manipulation. As research continues to progress, nanotechnology is expected to play an increasingly important role in various scientific and technological fields, driving innovation and discovery.

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TOWARDS A SUSTAINABLE FUTURE: INSIGHTS INTO RENEWABLE AND NONRENEWABLE ENERGY

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Abstract:

This chapter explores renewable and non-renewable energy resources, detailing their types, advantages, and disadvantages. It examines the environmental, economic, and social impacts of energy use and highlights the growing need for a sustainable energy transition. The paper also outlines the pivotal roles played by governments and individuals in promoting clean energy solutions and reducing dependence on fossil fuels. Through informed choices and coordinated actions, a more sustainable and equitable energy future can be achieved.

Keywords: Renewable Energy, Non-renewable Resources, Sustainability, Energy Transition. Environmental Impact

Introduction:

As the global population continues to grow and the demand for energy increases, understanding the differences between renewable and nonrenewable resources becomes crucial. These resources not only power our homes and industries but also play a significant role in shaping our environmental and economic future. This comprehensive guide explores what renewable and nonrenewable resources are, their examples, benefits, challenges, and the impact they have on our planet [1,2].

Energy sources that we use in our daily lives can be categorized in different ways based on their availability, whether they are conventional or non-conventional, and whether they are renewable or non-renewable.

1. Classification Based on Availability:

a. Primary Energy Resources: These are energy sources that we get directly from nature without needing to process them too much, such as

Fossil Fuels: Coal, natural gas,

Nuclear Fuels: Uranium,

Hydropower: Energy from water,

Solar Energy: Energy from the Sun,

Wind Energy: Energy from the wind,

Geothermal Energy: Heat energy from the Earth,

Ocean Energy: Energy from tides and waves,

Biomass Energy: Energy from organic materials like cow dung (gobar gas) and

Hydrogen Energy: Energy from hydrogen [3,4].

b. Secondary Energy Resources: These are energy sources made by processing or converting primary energy sources, such as Petrol, Diesel, Kerosene Oil: Processed from crude oil and CNG and LPG: Processed natural gases

2. Classification Based on Conventionality:

a. Conventional Energy Resources: These are traditional energy sources that have been used for a long time, mostly non-renewable.

Examples: Coal, Oil & Natural Gas.

b. Non-Conventional Energy Resources: These are newer energy sources that are more environmentally friendly and sustainable.

Examples: Solar Energy, Wind Energy, Hydro energy, Geothermal Energy & Biomass Energy.

3. Classification Based on Renewability:

a. Renewable Energy Resources: These are energy sources that can be naturally replenished and are considered eco-friendly. They are expected to play a big role in the future, as they can replace the depleting non-renewable sources. Examples: Solar Energy, Wind Energy & Geothermal Energy

b. Non-Renewable Energy Resources: These are resources that are limited and can't be replaced once used up. They are running out due to overuse, so finding alternatives is important. Examples: Oil and Natural Gas In simple terms, renewable resources like solar and wind are more sustainable and will help in reducing the use of depleting fossil fuels like coal and oil [5,6].

Renewable Resources

Renewable resources are natural things that we can use again and again because nature replaces them. They don't run out easily, and they're better for the Earth. We can use them for energy without harming the environment too much. Some examples of renewable resources are: Sunlight, Wind, Water (rivers, dams). Plants and organic waste (biomass) and Earth's natural heat (geothermal energy),

These resources help us make renewable energy—clean power that helps reduce pollution and fight climate change [7].

Fig. 1: Renewable Resources

Types of Renewable Energy

1. **Solar Energy (From the Sun)**

The sun gives us a lot of energy every day. We can collect sunlight using solar panels, which turn the light into electricity. This can be used to power homes, schools, and businesses.

- It's clean and safe.
- Works well in sunny areas.
- Helps save money on electricity bills.

Fig. 2: Solar Energy (From the Sun)

2. Wind Energy (From the wind)

Wind energy is becoming a big player in the world of renewable power. You've probably seen those tall wind turbines standing in open fields or along coastlines—they're not just for looks. They catch the wind and turn it into electricity. When the wind spins the blades, it powers a generator that makes energy. Wind power has really taken off in recent years, and it's helping supply more and more of the world's electricity. Offshore wind farms—those built out at sea—are especially promising because the wind is stronger and steadier out there. Besides being good for the planet by cutting carbon emissions, wind energy also creates jobs and boosts local economies.

When the wind blows, it moves the blades of big machines called wind turbines. These spinning blades create electricity.

- It doesn't cause air pollution.
- Works best in windy places like hills or coastal areas.
- Wind farms can power many homes.

Fig. 3: Wind Energy (From the wind)

3. Hydropower (From Moving Water)

Hydropower is one of the oldest and most reliable renewable energy sources. It works by using the movement of water—like from a river or dam—to turn turbines that generate electricity. Big dams store water and release it when needed, which means they can produce electricity whenever demand goes up. That makes hydropower flexible and dependable. While large dams can have environmental downsides, smaller hydropower systems are eco-friendlier and work well in rural or remote areas.

Hydropower uses the energy of moving water, like rivers or dams, to spin turbines and make electricity.

- It's reliable and used in many countries.

- Doesn't create harmful smoke or gases.
- Best used where there's a strong water flow.

Fig. 4: Hydropower (From Moving Water)

4. Biomass Energy (From Plants and Waste)

Biomass energy is made from things like plants, food scraps, and farming leftovers. By burning this organic material or breaking it down in other ways, we can produce heat, electricity, or even fuels for cars and trucks. Since we can keep growing new plants and crops, biomass is considered renewable—unlike coal or oil, which will eventually run out. Biomass is widely available and can be used in both small homes and big factories. But it's important to manage it responsibly, or we risk harming the environment, like by cutting down too many trees.

Biomass comes from things like wood, crops, food waste, and even animal manure. When we burn or process these materials, we can create heat or electricity.

- It's renewable because we can grow more plants.
- Helps reduce garbage.
- Can be used for heating, cooking, or making power.

Fig. 5: Biomass Energy (From Plants and Waste)

(ISBN: 978-93-48620-02-6)

5. Geothermal Energy (From Earth's Heat)

Geothermal energy comes from the heat stored deep inside the Earth. By drilling down into underground reservoirs, we can bring up hot water or steam, which is then used to produce electricity. One of the best things about geothermal power is that it runs 24/7—it's steady and reliable. Some places, like Iceland, use geothermal energy for a big chunk of their electricity and heating. As we keep exploring and improving the technology, geothermal energy could become more common in other parts of the world too.

Deep inside the Earth, it's very hot. We can use this heat, called geothermal energy, to make electricity or warm buildings.

- It works all the time, day and night.
- It's clean and doesn't harm the air.
- Best used in areas with volcanoes or hot spring

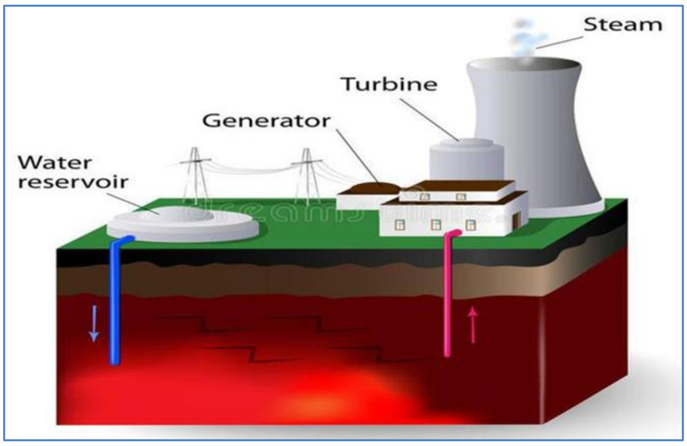

Fig. 6: Geothermal Energy (From Earth's Heat)

Upsides of Renewable Resources

1. Cleaner Air, Healthier Planet: Renewables like solar and wind don't release harmful gases, leading to cleaner air and a healthier environment.

2. More Jobs: The renewable energy sector creates many new jobs, boosting local economies and supporting communities.

3. Energy Independence: Using local resources like wind or sun reduces reliance on imported fossil fuels, making countries more energy secure.

4. Cheaper Over Time: The cost of solar panels and wind turbines has dropped, making renewable energy affordable in many areas.

5. A Balanced Energy Mix: Using various renewable sources creates a more stable and reliable energy system [8].

Downsides of Renewable Resources

1. Weather-Dependent: Solar and wind energy rely on weather, making their output less predictable.

2. Takes Up Space: Large renewable systems can use a lot of land, sometimes affecting nature and wildlife.

3. High Upfront Costs: Initial installation of renewable systems can be costly, despite future savings.

4. Storage Challenges: Storing energy for cloudy or windless days is still expensive and limited.

5. Impact on Nature: Dams and turbines can harm ecosystems, affecting fish, birds, and bats.

6. Location Limits: Not all areas have enough sun, wind, or water for efficient renewable energy.

7. Resource Location Limits: Some energy sources, like geothermal, are only available in specific regions.

8. Material and Resource Demand: Renewables need rare minerals, and mining them can damage the environment [9].

Why Should We Use Renewable Energy to the environment?

- It doesn't run out easily.
- It reduces pollution and slows climate change.
- It helps create green jobs and clean communities [10].

Transition from Non-Renewable to Renewable Energy Fossil fuels like coal, oil, and gas are harmful to the environment and are running out. Burning them releases greenhouse gases that cause climate change. Renewable energy sources, on the other hand, are cleaner and more sustainable. Switching to renewables helps reduce emissions, improve energy security, and protect the planet for future generations [11].

Renewable Energy Revolution

Renewable energy is growing fast. Thanks to better technology, strong government support, and public interest, we're seeing more solar panels and wind turbines than ever. In 2020, renewables provided about 26% of global electricity. That number is expected to rise to over 30% by 2024, showing a clear trend toward a cleaner energy future.

How Governments Are Helping

Governments around the world are helping speed up the switch to clean energy through various programs:

1. Renewable Portfolio Standards (RPS): These rules require a certain amount of electricity to come from renewable sources, encouraging growth in clean energy.

2. Feed-in Tariffs: People and companies get paid for generating renewable energy and adding it to the grid, turning homes into mini power stations.

3. Funding for Innovation: Governments invest in research to improve renewable energy technology, making it more efficient and affordable.

4. Global Agreements: International deals like the Paris Agreement push countries to reduce emissions and commit to renewable energy goals.

Future of Renewable Energy

The outlook for renewable energy is very positive. New technologies like smart grids and advanced batteries are making clean energy more efficient and easier to use. With innovation, policy support, and public action, renewables could soon become the main source of global power. This means a cleaner environment, better health, and a safer future for all.

Non-Renewable Resources

Nonrenewable resources are those that do not replenish at a sufficient rate compared to their consumption. They are finite and will eventually deplete. Examples include fossil fuels (coal, oil, natural gas), nuclear energy, and minerals such as gold and silver. Some Examples of Nonrenewable Resources are: Coal, Oil, Natural gas Nuclear energy and Minerals,

"These resources produce energy but cause pollution and climate change, as they can't be replaced once used."

Fig. 7: Non-Renewable Resources

Types of Non-Renewable Resources:

1. Coal: Coal is a type of fossil fuel that's been used for centuries, mainly to generate electricity and power industrial processes like steel production. It's widely available and relatively cheap, which makes it a popular energy source in many parts of the world. However, burning coal releases a large amount of carbon dioxide and other harmful pollutants into the air, making it one of the biggest contributors to climate change and air pollution. Coal is a fossil fuel that is used primarily for electricity generation and industrial processes. It is abundant but contributes significantly to carbon emissions and environmental pollution.

Fig. 8: Coal

2. Oil: Oil, also called petroleum, is a thick liquid found deep underground. We use it to make fuel for cars, planes, and trucks—like gasoline and diesel—as well as many products like plastics. It's a big part of modern life, but drilling for it can cause oil spills, which harm the environment. And when we burn oil, it releases greenhouse gases that warm the planet. Oil, or petroleum, is used to produce gasoline, diesel, and other petrochemical products. It is a key resource for transportation and various industries but poses environmental risks such as spills and greenhouse gas emissions.

3. Natural Gas: Natural gas is a cleaner-burning fossil fuel that's often used for heating homes, cooking, and generating electricity. It's also used in making products like fertilizers and chemicals. Even though it pollutes less than coal or oil, it still releases carbon dioxide, and leaks of methane (a powerful greenhouse gas) during drilling and transport can be very harmful to the climate. Natural gas is a fossil fuel used for heating, electricity generation, and as an industrial feedstock. It burns cleaner than coal and oil but still contributes to carbon emissions [7].

4. Nuclear energy: Nuclear energy is generated by splitting atoms in a process called fission, which releases a significant amount of energy. It provides a large amount of electricity with low greenhouse gas emissions but raises concerns about radioactive waste and safety.

Nuclear energy comes from splitting tiny atoms in a process called fission, which releases a lot of power. It can produce a huge amount of electricity without creating much air pollution. But there are concerns about radioactive waste, which stays dangerous for a long time, and the risks of accidents.

Fig. 9: Electricity Production by Nuclear Energy

5. Minerals: Minerals like gold, silver, and rare earth elements are used in things like phones, computers, buildings, and machines. They're really important for modern life, but they're limited. As they become harder to find, getting them out of the ground can become too expensive or harmful to the environment.

Minerals such as gold, silver, and rare earth elements are used in various industries, including electronics, construction, and manufacturing. These resources are finite and can become economically unviable as they become scarcer.

Fig. 10: Minerals

Upsides of Non-Renewable Resources

1. Energy Density: Fossil fuels provide a lot of energy from a small amount of fuel, making them highly efficient.

2. Infrastructure: We already have systems in place to extract, process, and distribute fossil fuels.

3. Stability: Non-renewables support economies by providing steady jobs and income.

4. High Energy Output: They produce enough energy to power entire cities, industries, and vehicles.

5. Well-Established Systems: Pipelines, power plants, and transport systems are already built and running.

6. Economic Importance: Fossil fuel industries bring in tax revenue and support business growth.

7. Economic Driver: Millions of jobs rely on fossil fuels across many countries.

8. Lower Upfront Costs: Starting fossil fuel plants costs less initially than renewable alternatives.

Downsides of Non-Renewable Resources

1. They Will Run Out: These fuels take millions of years to form and can't be quickly replaced.

2. Pollution: Burning them releases gases that pollute the air and harm the environment.

3. Climate Change: Carbon emissions trap heat, causing global warming and extreme weather.

4. Health Problems: Air pollution from fossil fuels can cause breathing issues and disease.

5. Environmental Damage: Mining and drilling destroy land and harm ecosystems and wildlife.

6. Economic Risks: Supply limits and price changes can cause financial instability.

7. Energy Insecurity: Relying on imported fuels can lead to political tension and supply issues.

Future Energy: Moving from Non-renewable to Renewable Energy

1. Support from Governments: Governments can help by offering tax breaks, subsidies, and setting clean energy goals. These actions make going green easier and more affordable.

2. Technology: Advances in solar panels, wind turbines, and batteries are making clean energy cheaper and more reliable. Smart grids help deliver energy efficiently.

3. Education and Awareness: People are more likely to support clean energy when they understand the environmental benefits and the problems caused by fossil fuels.

4. Upgrading Infrastructure: We need better power grids, energy storage, and local systems to fully support renewable energy. These upgrades improve reliability.

5. Working Together: Transitioning works best with teamwork. Governments, businesses, and communities must share ideas and resources to move faster and smarter.

Role of Fossil Fuels in the Transition Period

1. Bridging Energy Demand: Fossil fuels help meet energy needs while renewable systems grow. They fill in gaps when wind or solar is not available.

2. Support for Development: Revenue from fossil fuels is being used to build renewable systems. Old fossil fuel plants are also being updated to pollute less.

3. Energy Security and Stability: In places with weak renewable supply, fossil fuels keep the lights on and prevent blackouts.

4. Technological Integration: Natural gas, a cleaner fossil fuel, is used with renewables to balance energy supply and demand quickly and effectively.

5. Economic and Political Role: Many countries rely on fossil fuels for jobs and income. Gradual change helps avoid economic shocks and supports a smooth transition.

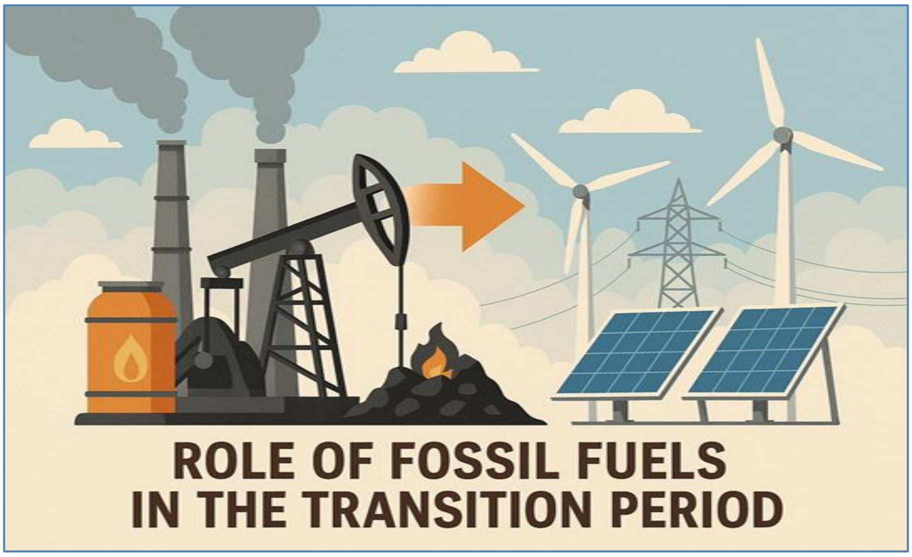

Fig. 11: Role of fossil fuels in transition period

Non-Renewable Resources: A Rising Concern

Non-renewable resources like coal, oil, and natural gas are being used more than ever, but they take millions of years to form and can't be replaced once they're gone. While they power much of our electricity, transport, and heating, they also cause pollution and contribute to climate change. If we don't reduce our dependence on these fuels and switch to cleaner energy sources like solar and wind, we could face serious environmental damage and future energy shortages [12].

How government are helping?

The government is trying to help by using more clean energy like solar and wind instead of oil and coal. They support green energy projects, make rules to reduce pollution, and teach people how to save energy. They also build better buses and trains so people don't need to drive as much. All of this is to protect the planet and make sure we have energy in the future.

1. Promoting clean energy – They support solar, wind, and other renewable energy sources.

2. Giving incentives – They give money or tax benefits to people and companies that use or produce clean energy.

3. Making laws – They create rules to limit pollution and control how much non-renewable energy can be used.

4. Improving public transport – They build better bus and train systems to reduce car use and save fuel.

5. Spreading awareness – They run campaigns to teach people how to save energy and use it wisely.

6. Investing in research – They fund new technologies that can replace oil, gas, and coal.

7. Encouraging recycling – They promote recycling to reduce the need for new materials and save energy.

8. Setting goals – They make long-term plans to slowly move away from non-renewable resources.

A Finite Path: The Climb in Non-Renewable Resource Use

- We use more coal, oil, and gas every year, these take millions of years to form and can't be replaced quickly.
- Burning them causes pollution and global warming, if we keep using them, we may face energy shortages and a hotter planet.

How Governments Are Helping

1. Governments support clean energy like solar and wind, they give tax breaks and rewards to users and producers.
2. Laws are made to reduce pollution and limit fossil fuel use; better public transport helps people use less fuel.

(ISBN: 978-93-48620-02-6)

3. Campaigns teach people how to save energy, funds go to research for new clean energy technology.
4. Governments also promote recycling and set long-term energy goals.

Future of Non-Renewable Resources

- Fossil fuels are running out, they will be harder and more expensive to find.
- Using them harms the planet, that's why countries are switching to clean, endless energy like solar and wind.

Role of the Individual

1. Everyone can help by saving energy and using clean power.
2. Turn off unused lights and appliances, use energy-saving bulbs and devices.
3. Walk, cycle, or use public transport, carpool to save fuel.
4. Recycle and avoid plastic, support solar and green energy if you can.
5. Talk to others about clean energy, buy eco-friendly and local products.

Role of Government and Policies

1. Governments make laws to protect nature. They ensure fair use of resources.
2. They support clean energy, tree planting, and wildlife conservation.
3. Policies guide industries to use resources wisely. Agencies check for pollution and punish violations.
4. They also educate the public and join global climate efforts.

Sustainable Energy Solutions

Sustainable energy is clean and lasts forever, it helps stop climate change and protects the Earth.

Key Sources of Sustainable Energy

Solar Power: Turns sunlight into electricity.

Wind Power: Uses wind turbines to generate power.

Hydropower: Uses water to create energy.

Geothermal: Uses Earth's heat for power and warmth.

Biomass: Made from plants and waste materials.

Energy Storage and Smart Grids

Energy Storage saves extra energy for later. Helps balance supply and demand.

Smart Grids manage power with data and tech. They track use, prevent outages, and support renewables.

Types of Popular Storage

1. Lithium-ion batteries

2. Pumped hydro
3. Thermal and compressed air systems

Future Trends in Energy

- Clean energy like solar and wind will grow fast, smart homes and cars will save energy automatically.
- Big batteries will store power for later use. more vehicles will run on electricity.
- AI will help cut waste and improve energy use [13].

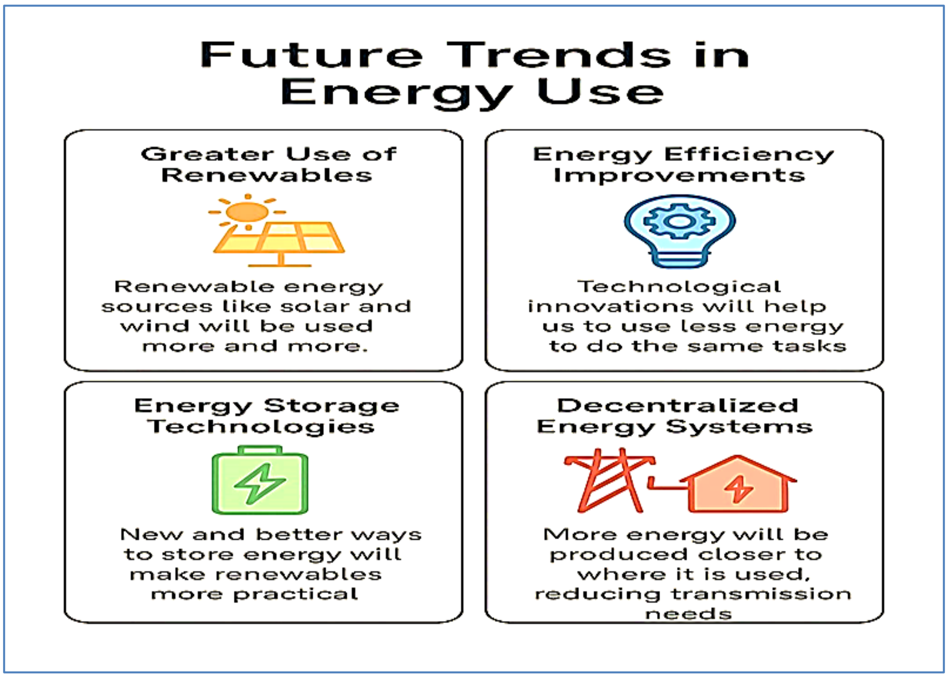

Fig. 12: Future Trends in Energy Use

Conclusion:

In today's world, understanding renewable and non-renewable energy is vital for a sustainable future. As climate change worsens and fossil fuels run low, shifting to clean, infinite sources like solar and wind reduces pollution and ensures long-term energy security. This transition not only protects the planet but also drives innovation and economic growth. By using energy wisely and spreading awareness, individuals and communities can help build a greener future. We must act now to choose renewable energy, cut waste, and inspire others—because renewable energy isn't just the future, it's the power to create a better tomorrow.

We must act now by choosing renewable energy, cutting waste, and inspiring others to protect our planet. Only then can we create a cleaner, greener, and more energy-secure future for everyone. Renewable energy isn't just the future—it's the present with the power to build a better tomorrow.

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EXPLORING GENERATIVE AI AND COMPUTATIONAL INTELLIGENCE FOR BREAST CANCER DETECTION: A HYBRID APPROACH

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Abstract:

Mammogram is one of the methods in understanding the presence of Microcalcification (MC) in the breast of women. MC is an initial form of breast cancer. With the help of mammogram image, a doctor can understand an approximate amount of MC present in the breast. Many analytical methods have been developed to quantify the amount of MC from the mammogram image. Such analytical methods can help in Computer Aided Detection (CAD) of MC. Commercial software's have been developed to encircle the MC locations. However, there is no guarantee that the information highlighted by the software as MC is real MCs. Many researchers have worked on the implementation of computer aided diagnosis (CAD) of MC. In this research work, the mammogram image is decomposed using wavelet filters. Daubechi wavelet has been used to decompose the given mammogram image into 5 levels. In each level of decomposition, the approximation is further decomposed. Statistical features are calculated from the approximations of each image from each level of decomposition. These statistical features form training patterns and testing patterns of the proposed ANN algorithms. The patterns are used as inputs for the Back-Propagation Algorithm (BPA), echo state neural network algorithm, Fuzzy logic algorithm and Firefly algorithms. Ten mammogram images are used from Mammographic Image Analysis Society (MIAS) database. Two thousand unique patterns are obtained from the 10 images.

From the 2000 patterns, 1000 patterns are used for training the BPA/ESNN/FL/FF. The remaining 1000 patterns are used for testing the BPA / ESNN/FL/FF algorithms. In the training patterns, 500 are with MC and remaining 500 are without MC. In the testing patterns, 500 are with MC and remaining 500 are without MC. Performance of the algorithms is assessed by receiver operating characteristic curve, sensitivity, specificity and accuracy.

The major contribution of the research work is as follows:

1. BPA is combined with wavelets to detect the presence of MC.
2. ESNN is combined with wavelets to detect the presence of MC in mammogram image.
3. The accuracy of FF and ESNN with wavelet in detecting the MC is higher when compared to that of BPA and FL with wavelets.

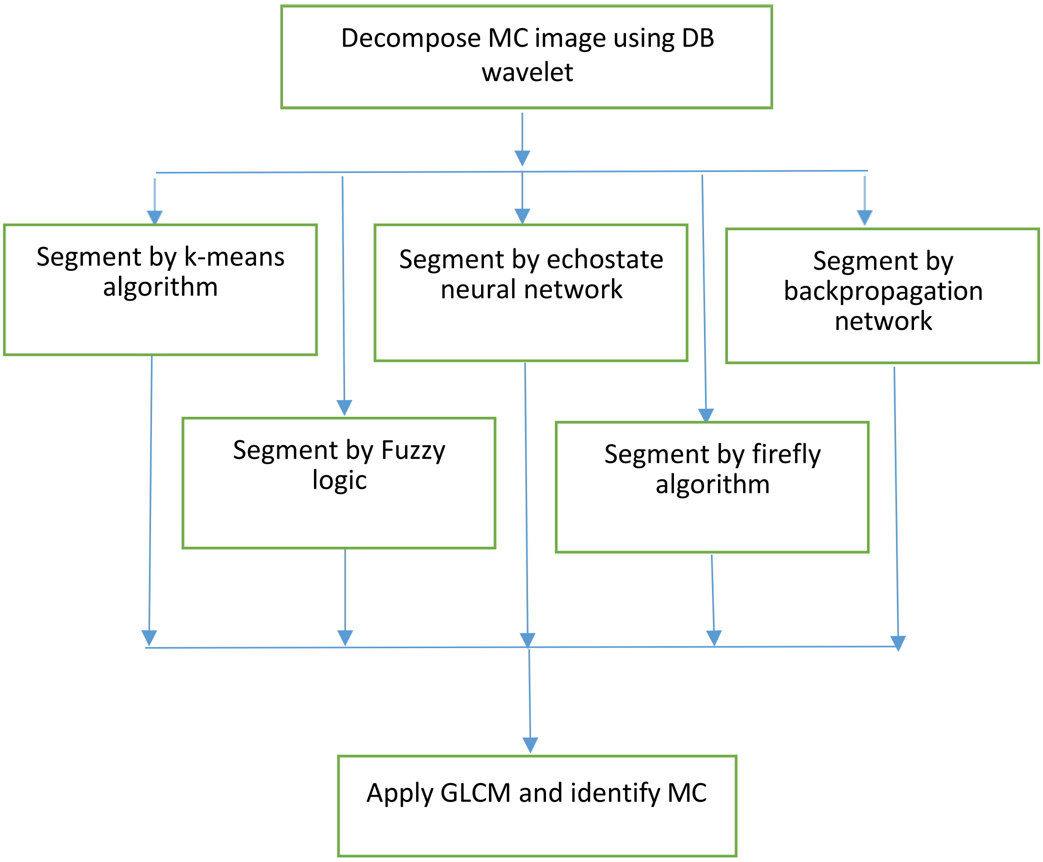
Introduction:

Breast cancer is one of the main causes of death in women. Early diagnosis of the human body is an important means to reduce the mortality rate. Mammography is one of the most common techniques for breast cancer diagnosis. Microcalcification (MC) is one among several types of unwanted objects that can be detected in a mammogram. MC is calcium accumulations of 100 microns to several mm in diameter. These are early indicators of the presence of breast cancer. MC clusters are groups of three or more MCs that usually appear in areas smaller than 1cm2, with a probability of becoming a malignant lesion.

Calcification in the breast can be seen on a mammogram but cannot be detected by touch. There are two types of breast calcification Macrocalcification and MC. Macrocalcifications are large deposits and are usually not related to cancer. MCs are specks of calcium that may be found in an area of rapidly dividing cells. Many MCs clustered together may be a sign of cancer.

Problem Statement

MC is not a regular structure. The density of MC is not uniform with a breast and among different breasts. Identification and quantification of MC to the maximum possible extent in a mammogram breast image is still only an approximate amount of MC quantification. This research work proposes intelligent methods to increase the accuracy of MC quantification.



Schematic flow for MC identification in breast image

Steps for MC Identification in Breast Image

1. Input mammogram image.
2. Preprocessing the image.
3. Applying decomposition using wavelets.
4. Obtain statistical features and form a pattern.
5. For each image obtain patterns for training and testing ANN.
6. By using training patterns, store final weights of the ANN at the end of training.
7. During testing process, adopt steps 1-4. Process with the final weights as obtained in step 6.

   The outputs of the ANN is used to assess the presence of type of MC.

Objectives

1. To identify the presence of smallest possible MC.
2. To minimize false positive rate and increase the accuracy of the MC identification.

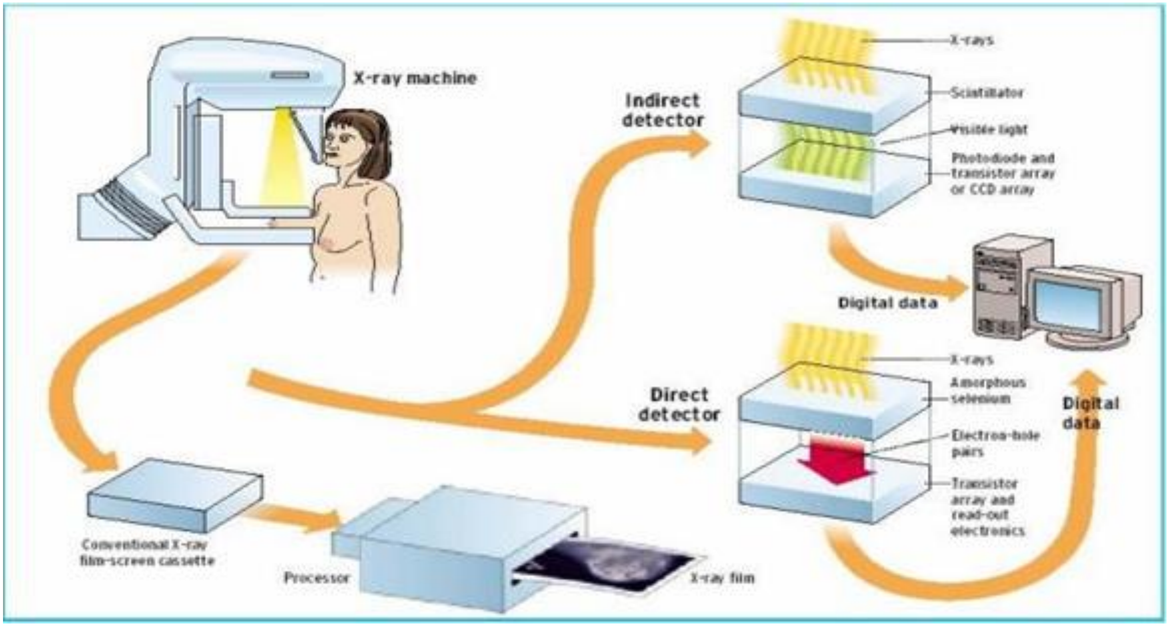
Methodologies

1. Extracting features using Daubechi wavelet.
2. Identify MC using features extracted from Wavelet and with Back propagation algorithm.

3. Identify MC using features extracted from Wavelet and with Echo state Neural Network.
4. Identify MC using features extracted from Wavelet and with Fuzzy Logic algorithm.
5. Identify MC using features extracted from Wavelet and with Firefly algorithm

Description of Breast Anatomy

A computer system intended for MC detection in mammograms may be based on several methods, like wave lets, fractal models, support vector machines, mathematical morphology, Bayesian image analysis models, high order statistic, and fuzzy logic. Many filters are available for noise reduction in the image. Difference of Gaussian (DoG) fillters is adequate for the noise-invariant and size specific detection of spots, resulting in a DoG image. The use of DoG for detection of potential MCs has been addressed successfully by Osslan Osiris *et al.* (2008).



Film-Screen and Digital Mammography.

Courtesy: http://www.spectrum.ieee.org/WEBONLY/pressrelease/0501/cancer0501.pdf

In all types of mammography, the x-ray photons are given off by the x-ray source and directed towards the patient. In conventional mammography, the development of a film screen cartridge produces the mammogram and is shown in Figure 1.2. In digital mammography, detection can be done in two ways. With indirect detection, x- rays pass through the patient's breast and hit the scintillator. A scintillator is a material that converts x-ray energy into visible light. The scintillator is coupled to a photodetector array or connected to tiles of charge-coupled devices (CCDs) by taped optical fibers. Needle like crystals of cesium iodide (CsI) is typically used as a scintillator. An amorphous silicon detector made up of photodiodes, and a thin-film transistor (TFT) is used as the readout circuitry. As illustrated in Figure 1.2, with direct detection, the original CCD based indirect system is replaced by amorphous silicon TFT array coated in amorphous selenium. A voltage is placed across the selenium, and wherever an x-ray strikes it, electron-hole pairs are formed. These pairs are then collected by integrated capacitors associated with the pixel elements of the TFT array, and the image is read out by electronics integrated in the array.

Digital Mammogram

Film-screen mammography has saved many lives and it is considered the imaging modality of choice for early detection of breast cancer. Digital mammography provides excellent image quality and has a number of advantages as compared to film-screen mammography systems. Some of these advantages are the potential to acquire the images faster, easily store the images; to manipulate the contrast and magnification of the images, and the potential for digital post processing of the acquired images. One of the limiting problems with conventional mammography is that the recorded image represents the superposition of a three- dimensional (3D) object (i.e., the breast) onto a two-dimensional (2D) plane. Even though breast compression is done, normal anatomical structure can combine with useful diagnostic information (e.g., a tumor mass) in such a way as to impede visualization and reduce lesion detectability.

Breast cancers cause symptoms that tend to be larger, and they may have already spread beyond the breast. In contrast, breast cancers found during the screening process are smaller and they confined to the breast. The size of a breast cancer and how far it has spread are the most important factors in predicting the prognosis (outlook) of a woman with this disease. Most doctors feel that early detection tests for breast cancer can save thousands of lives if more women and their health care providers adopt these tests.

Microcalcification

Existing purpose of mammography is to

1. Early detection of breast cancer, through detection of characteristic masses

2. Detection of MCs.

Existing methods have achieved certain degrees of success in their particular applications. The percentage of FN and FP errors is still too high when using conventional CAD systems. Many solutions have often tended to focus on more sophisticated image processing algorithms for reducing FN and FP errors by providing incremental improvement over existing methods. Thus, there exists a need for an accurate automated method for identifying and assessing clustered structures in a medical image.

Among the characteristics employed by diagnosticians in working with x-ray images of the breast, the following guidelines can be considered:

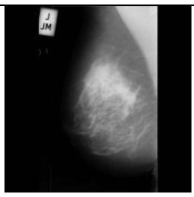
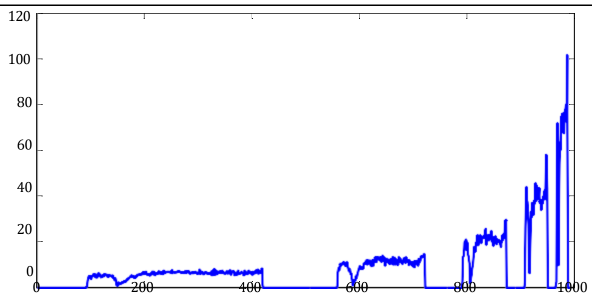
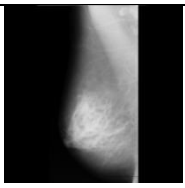
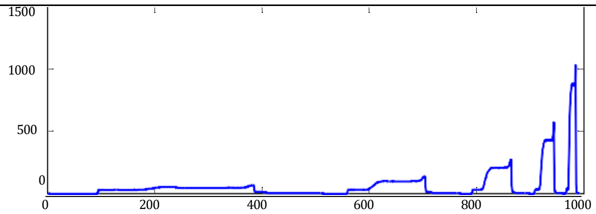
1. Large (>1 mm diameter), coarse calcifications are likely to be benign, but malignant MCs tend to be punctuate, 0.5 mm or smaller;
2. Single calcifications are more likely to be benign;
3. Rounded calcifications of equal size are likely to be benign;
4. Calcifications scattered through both breasts are more likely to be associated with benign disease;
5. Groups of calcifications of mixed size with irregular shapesare morecharacteristic of malignant than benign condition;
6. Employing these characteristics, Clusters of fine calcifications are more likely to signify malignancy;
7. Rows of fine calcifications within the ducts are likely to signify malignancy
8. Short rods of calcification, particularly if they branch, are highly likely to signify malignancy;
9. Grossly irregular whorled cluster shapes are likely to signify malignancy; and
10. In malignant calcification clusters, the average distance between calcifications is typically less than 1 mm.

Image analysis methods used in Computer Aided Diagnostics (CAD) systems extract and quantify image data relating to shape, edge character, and intensity at both the spot and cluster level. The shape can be characterized according to its geometric features such as compactness, perimeter, elongation, ratio of moments, and eccentricity. The edge character shows the comparison of the calcification with its background, which can be analyzed by the gradient of the spot boundary and the contrast between the spot and the background. The intensity-based features of the calcification include the mean intensity of a spot as well as the maximum intensity, the deviation of the intensity, the moment, and the like.

Image Decomposition Using Wavelets

The wavelet (WT) was developed as an alternative to the short time Fourier transform (STFT). A wavelet is a waveform of effectively limited duration that has an average value of zero. Compare wavelets with sine waves, which are the basis of Fourier analysis. Sinusoids do not have limited duration, they extend from minus to plus infinity and where sinusoids are smooth and predictable, wavelets tend to be. Wavelet analysis is the breaking up of a signal into shifted and scaled versions of the original (or mother) wavelet. Mathematically, the process of Fourier analysis is represented by the Fourier transform: which is the sum over all time of the signal f(t) multiplied by a complex exponential. The results of the transform are the Fourier coefficients, which when multiplied by a sinusoid of frequency, yield the constituent sinusoidal components of the original signal.

The continuous wavelet transform (CWT) is defined as the sum over all time of the signal multiplied by scaled, shifted versions of the wavelet function. The result of the CWT is many wavelets coefficients C, which are a function of scale and position. Multiplying each coefficient by the appropriately scaled and shifted wavelet yields the constituent wavelets of the original signal.

Mammogram and its coefficient		
IMAGE NUMBER	**IMAGE**	**Five level decomposition** **Each plot, x-label represents five levels of decomposiiton and y-label represents coefficients**
209		
211		

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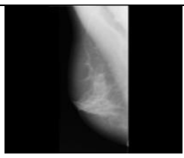
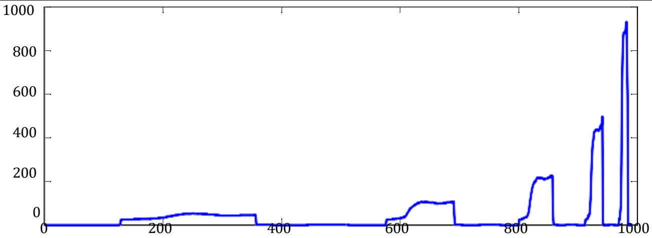
<tr><td>213</td><td></td><td>
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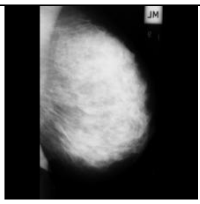
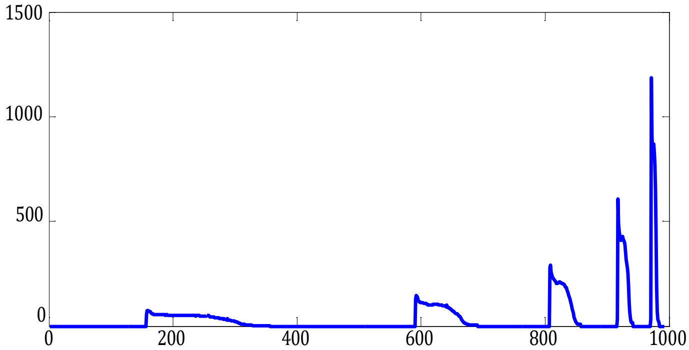
<tr><td>216</td><td></td><td>
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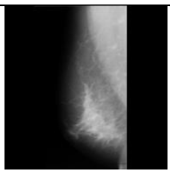
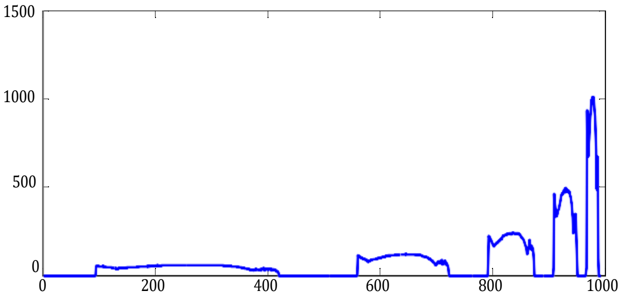
<tr><td>233</td><td></td><td>
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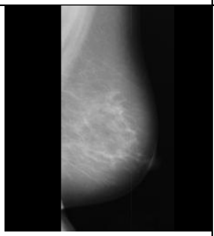
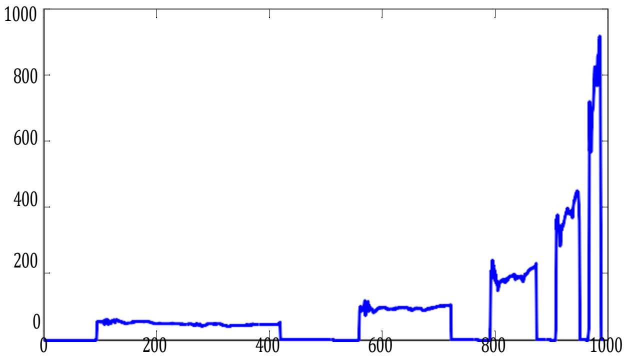
<tr><td>238</td><td></td><td>
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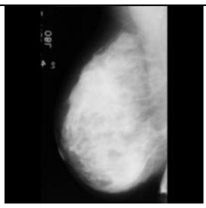
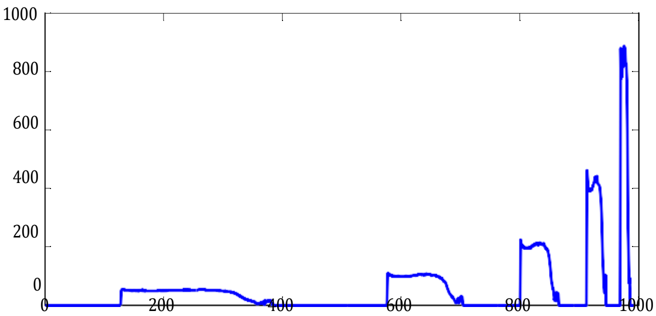
<tr><td>239</td><td></td><td>
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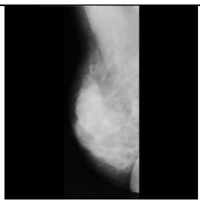
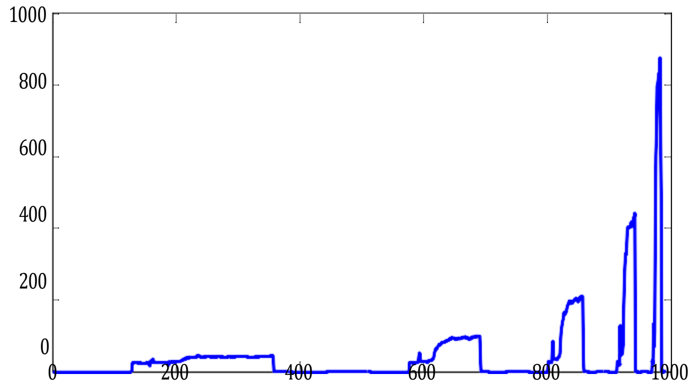
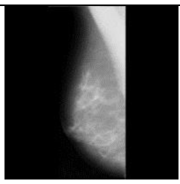
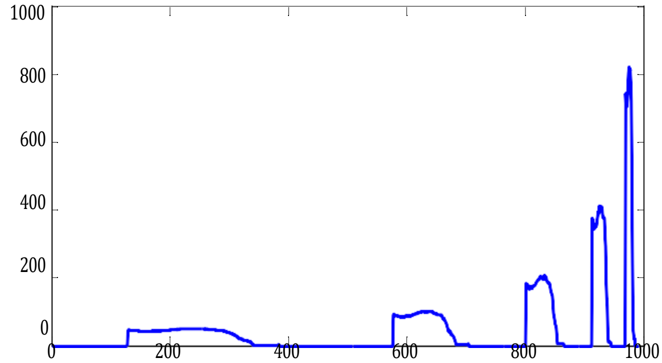
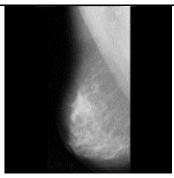
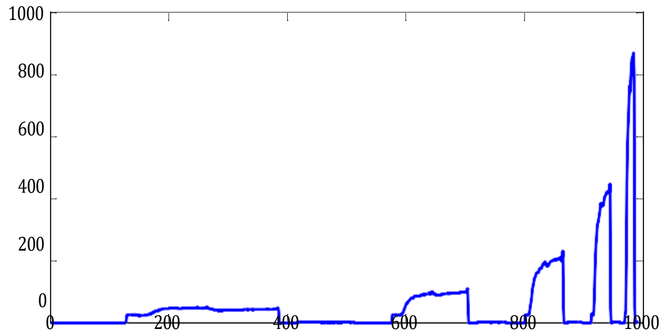
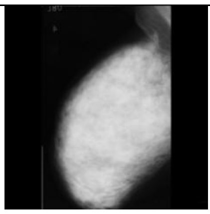
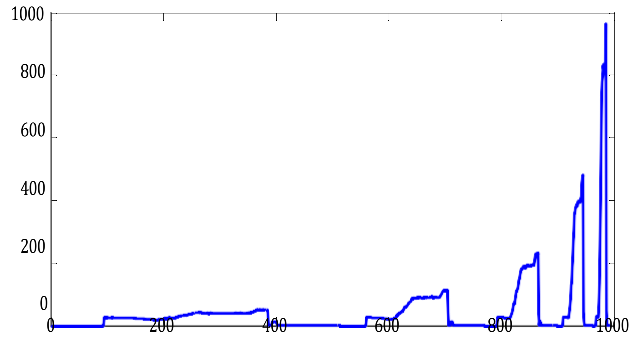
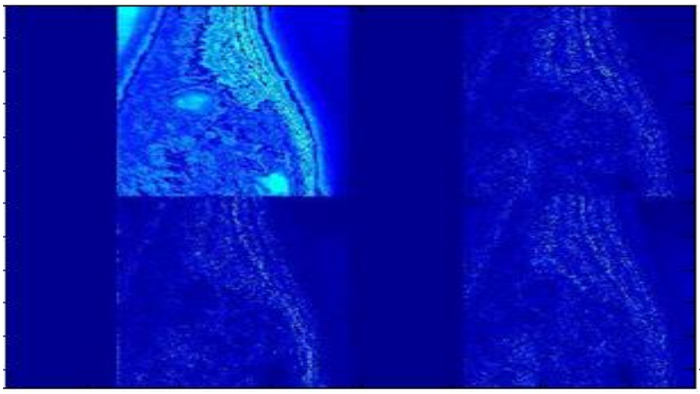
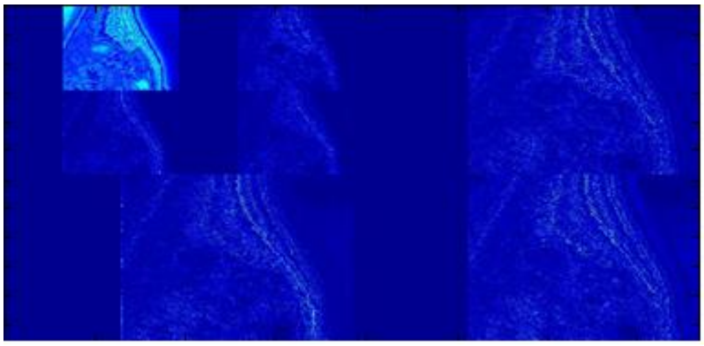
241		
245		
249		
253		



Level-1 decomposition



Level-2 decomposition

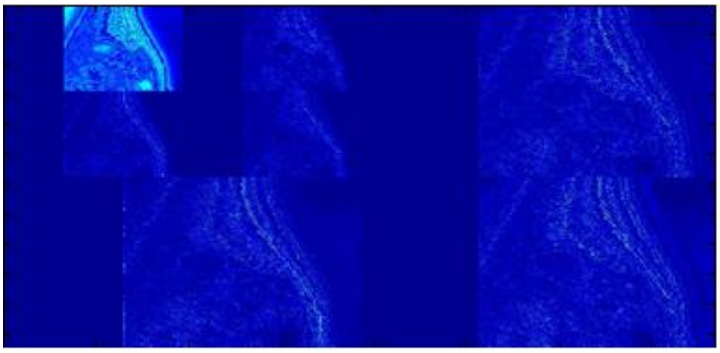
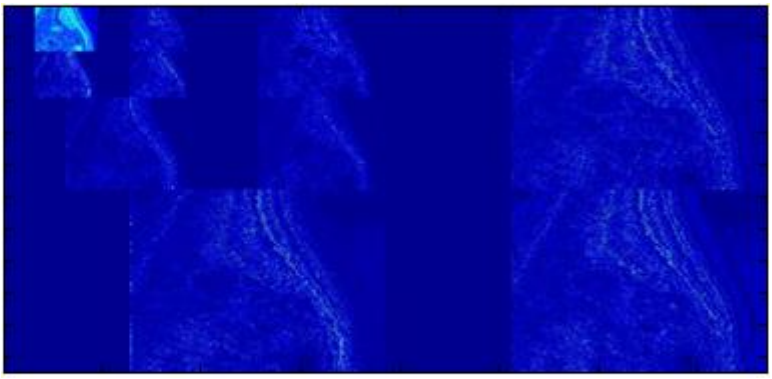
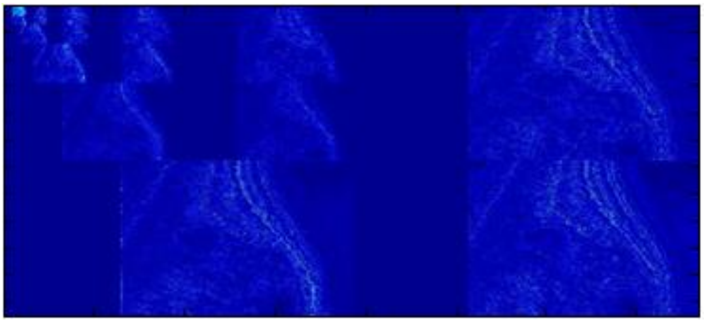


Fig.3.5 Level-3 decomposition



Level-4 decomposition



Level-5 decomposition

Artificial Neural Network (ANN)

An Artificial Neural Network (ANN) is an abstract simulation of a real nervous system that contains a collection of neuron units, communicating with each other via axon connections.

Steps involved in training the BPA Forward Propagation:

Step 1: The weights of the ANN are initialized.

Step 2: The inputs and outputs of a training pattern are presented to the network. The output of each node in the successive layers is calculated using equation

o(output of a node) = 1/(1+exp(-Σwij xi))

Step 3: The error of a pattern is calculated using equation.

E(p) = (1/2) Σ(d(p) – o(p))2

Reverse Propagation (Weight updation)

Step 4: The error for the nodes in the output layer is calculated using equation.

(output layer) = o(1-o)(d-o)

Step 5: The weights between output layer and hidden layer are updated using equation.

W(n+1) = W(n) + η(output layer) o(hidden layer)

Step 6: The error for the nodes in the hidden layer is calculated

⍰(Hidden layer) = o(1-o) ⍰⍰(output layer) W(updated weights between hidden and output layer)

Step 7: The weights between hidden layer(s) and input layer are updated using equation.

W(n+1) = W(n) + η(hidden layer) o(input layer)

The above steps complete one weight updation.

Second pattern is presented and the above steps are followed for the second weight updation. When all the training patterns are presented, a cycle of iteration or epoch is completed. The errors of all the training patterns are calculated using equation.

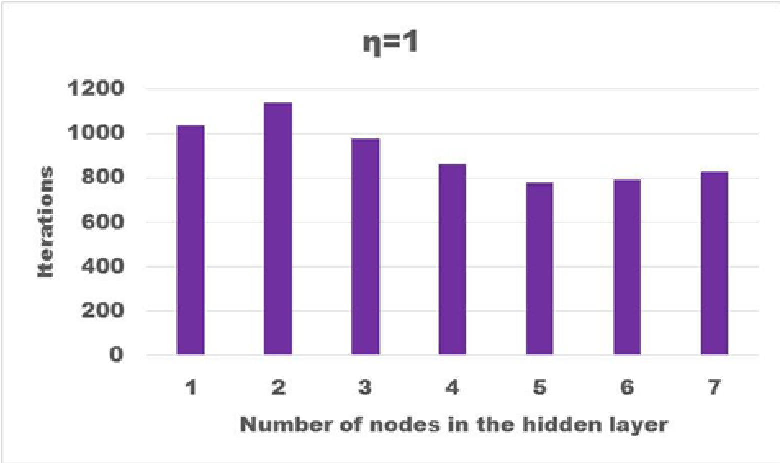
E(MSE) = Σ E(p)

Results and Discussions:

Convergence curve and the percentage of MC detection by BPA

The weight updating algorithm incorporates various parameters to update the weights of the connection strength matrices between input and hidden layer, hidden and output layers. The various parameters used in the BPA algorithms are as follows: α is an accelerating factor (>0 and <=1)

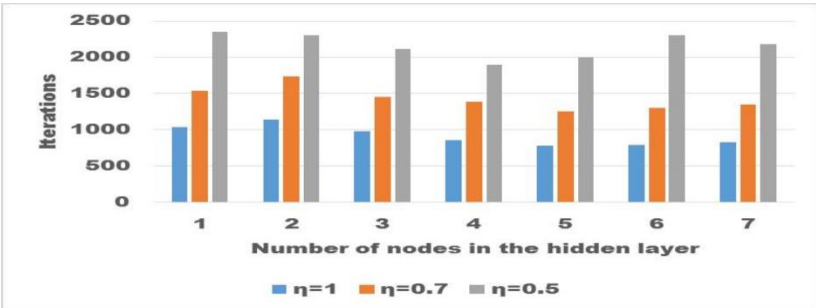
η is a learning factor (>0 and <=1)



Effect of number of nodes in the hidden layer for the ANN trained by using BPA

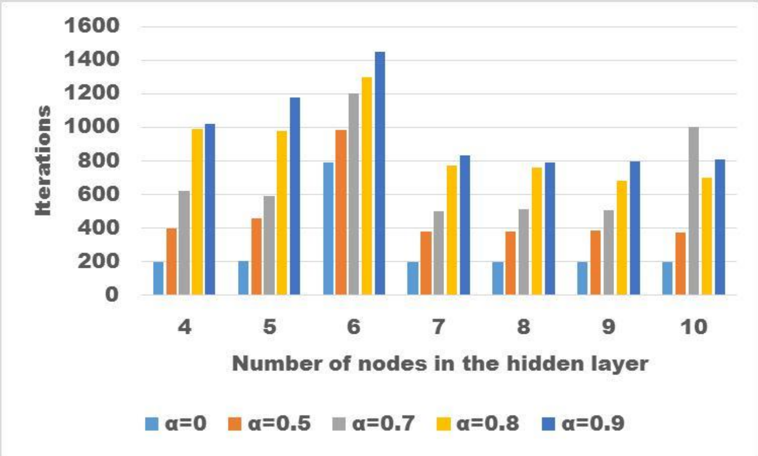
The initialization of the weights and the thresholds are in the range of 0.25 to 0.47. The iterations required by the network which are trained by using BPA for different number of nodes in the hidden layer to reach MSE of 0.01, are shown in Figure 4.4.

Number of hidden layer=1 and the =1. X-axis presents number of nodes in one hidden layer.



Effect of η in the ANN trained by using BPA

The learning factor η is supposed to guide the convergence rates of the network to the desired MSE with less number of iterations. It so happens, that sometimes η will make the network to converge to the desired MSE after an increased number of iterations. For 6 nodes in the hidden layer it requires 791 iterations for the network to reach MSE of 0.01 when η is 1.0 and 2300 iterations for the network to reach MSE of when η is 0.05. The convergence rates of the network for various numbers of nodes in one hidden layer for different values of η is shown in Figure 4.5

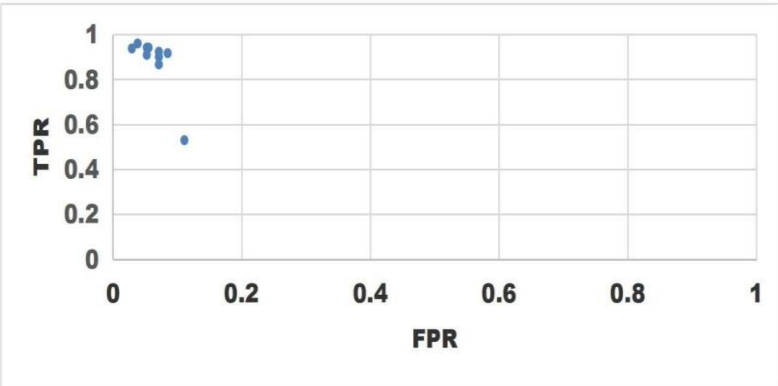


Receiver Operating Characteristics Curves

ROC is the plot between false positive rate and true positive rate. The points plotted here represent the performance of an algorithm in meeting the expected criteria, it is 90% or above.

When mammogram image is presented to algorithm, how well an algorithm is able to identify the presence of MC to the maximum extent, and how much the algorithm wrongly detects MC. The explanation for TP, TN, FP, and FN are as follows:

1. True positive (TP) - If the pattern contains MC and if the proposed algorithm detects the presence of MC, then it is true positive.
2. False negative (FN)- If the pattern contains MC and if the proposed algorithm does not detect the presence of MC, then it is False negative.
3. True negative (TN): If the pattern does not have MC and if the proposed algorithm does not detect MC, then it is true negative.
4. False positive (FP): If the pattern has no MC and if the proposed algorithm detects the presence of MC, then it is false positive.



ROC plot for BPA

The above figure presents the plot for FPR versus TPR. The points obtained are above the diagonal. Hence, the BPA is suitable for detecting MC in mammogram image.

Echo State Neural Network with Wavelet for Segmentation:

Training ESNN

Algorithm for Training ESNN

Step 1: Input the features from Wavelet

Step 2: Decide the number of reservoirs =21 or 22.

Step 3: Decide the number of nodes in the input layer = 5.

Step 4: Decide the number of nodes in the output layer = number of target values=1.

Step 5: Initialize state vector (number of reservoirs) =0.

Step 6: Initialize random weights between input layer (IL) and hidden layer (hL). Initialize weights between output layer (oL) and hidden layer (hL). Initialize weights in the reservoirs.

Step 7: Calculate state_vectornext = tanh ((ILhL)weights*Inputpattern + (hL)weights* state vectorpresent+ (hLoL)weights * Targetpattern).

Step 8: Calculate, a = Pseudo inverse (State vector all patterns).

Step 9: Calculate, W_{out} = a * T and store W_{out} for segmentation.

Testing ESNN with wavelet

Algorithm for Testing ESNN or segmenting the image

Testing ESNN (Segmenting image)

Step 1: Input the features from wavelet

Step 2: Decide the number of reservoirs =21 or 22.

Step 3: Calculate state vector = tanh ((ILhL)weights*Inputpattern + (hL)weights* state vectorpresent+ (hLOL) weights * Target pattern).

Step 4: Estimated output = state vector * W_{out}.

Step 5: Assign '0' (black) or '255' (white) in the new matrix which will be the segmented image.

Segmentation Performance in Terms of Number of Pixels and Number of Objects

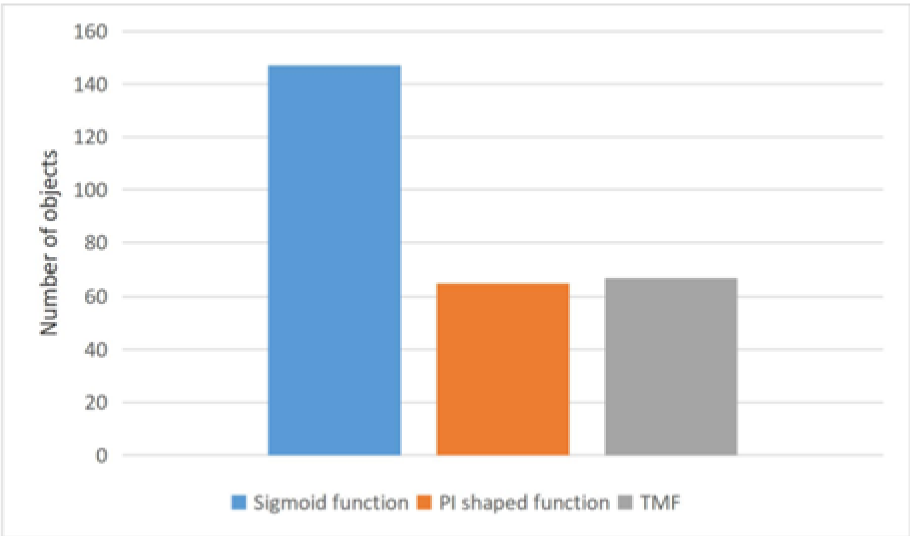
Segmentation Accuracy based on Number of Pixels			
Image	**NC**	**TP (Ground truth)**	**Apixel (%)**
Image 1	344	362	95.01
Image 2	1009	1062	94.99
Image 3	760	792	96.01
Image 4	843	892	94.56
AVERAGE			95.137

Segmentation Accuracy based on Number of Objects

Image		Solidity	Area	Perimeter	Total	Aprop
Image 1	Segmented	153.8936	227	126.3849	507.2785	
	Unsegmented	170.8582	245	138.3848	554.243	
Image 2	Segmented	132.5644	1439	867.1724	2438.7368	94.93
	Unsegmented	135.5644	1509	924.42	2568.9844	
Image 3	Segmented	170.875	1204	886.2178	2261.0928	96.23
	Unsegmented	175.876	1252	921.7996	2349.6756	
Image 4	Segmented	180.809	979	830.7306	1990.5396	94.32
	Unsegmented	190.701	1039	880.71	2110.4110	
Average:						95.20

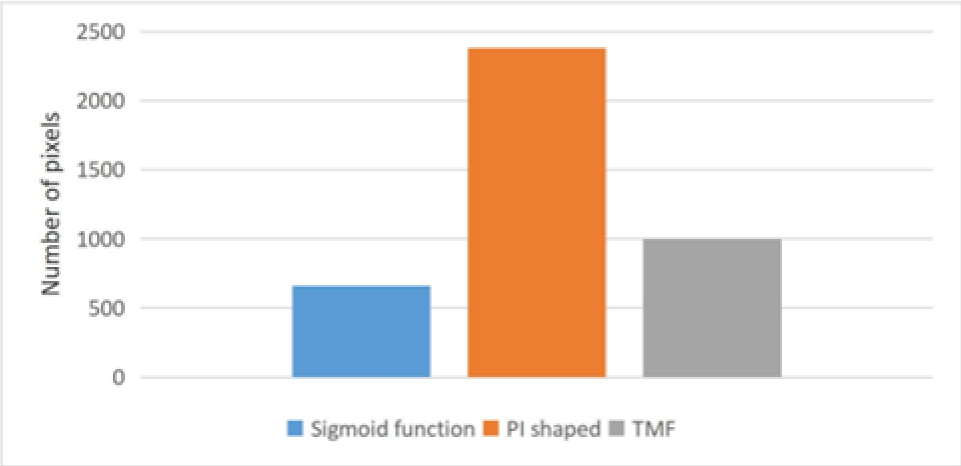
Fuzzy Logic for Mammogram Segmentation

Number of segmented objects and number of segmented pixels



Segmented Objects for different membership functions for image-1

The below figure shows the number of objects calculated using region properties of Matlab image-1. The number of objects obtained from segmented images for different membership functions is shown. Optimum number of objects that is 67 is obtained when the triangular membership function is used.



Segmented Pixels for different membership functions image-1

Firefly Algorithm for Segmentation of Mammogram Image

The firefly algorithm (FA), proposed by Xin-She Yang at Cambridge University, is a novel metaheuristic, which is inspired by the behavior of fireflies. Their population is estimated about two thousand firefly species.

FA uses the following three idealized rules:

1. Fireflies are unisex so that one firefly will be attracted to other fireflies regardless of their sex.
2. The attractiveness is proportional to the brightness, and they both decrease as their distance increases. Thus for any two flashing fireflies, the less bright one will move towards the brighter one. If there is no brighter one than a particular firefly, it will move randomly.
3. The brightness of a firefly is determined by the landscape of the objective function. As a firefly's attractiveness is proportional to the light intensity seen by adjacent fireflies, we can now define the variation of attractiveness with the distance r by equation.

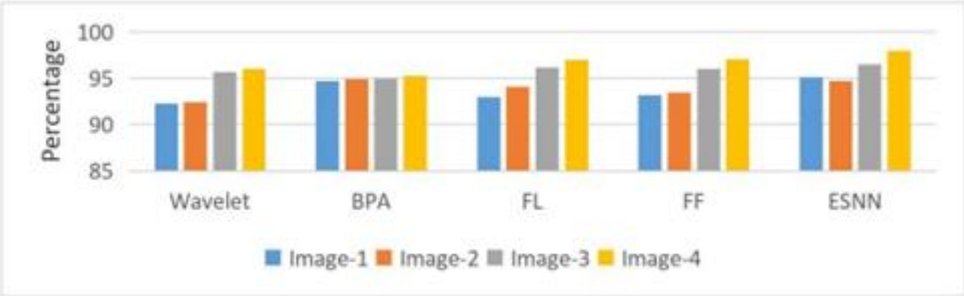
r = $^{-2}$

Where is attractiveness and r=0.

The movement of a firefly 'i' is attracted to another more attractive (brighter) firefly 'j' is determined by equation .

$^{+1}$ = + $^{-r_i 2}$(-) +

Where the second term is due to the attraction. The third term is randomization with being the randomization parameter, and is a vector of random numbers drawn from a Gaussian distribution or uniform distribution at time t. If, it becomes a simple random walk.



Segmentation accuracy for wavelet, BPA, FL, FF, ESNN

Texture Based Feature Extraction Using Gray Level Co-Occurrence Matrix (GLCM)

For every new occurrence of white pixels and new position of the moving window, the calculation of GLCM features, comparison with the template file, obtaining the lowest Euclidean distance and comparing it with the MC detection threshold is carried out. By adopting the above procedure, the presence or absence of MC in a mammogram can be analysed.

Algorithmic steps

Step 1: Input black and white images are given from wavelet, BPA, FL, FF and ESNN.

Step 2: Locate the white region from the segmented image.

Step 3: Correspondingly crop 40 x 40 window in the original image.

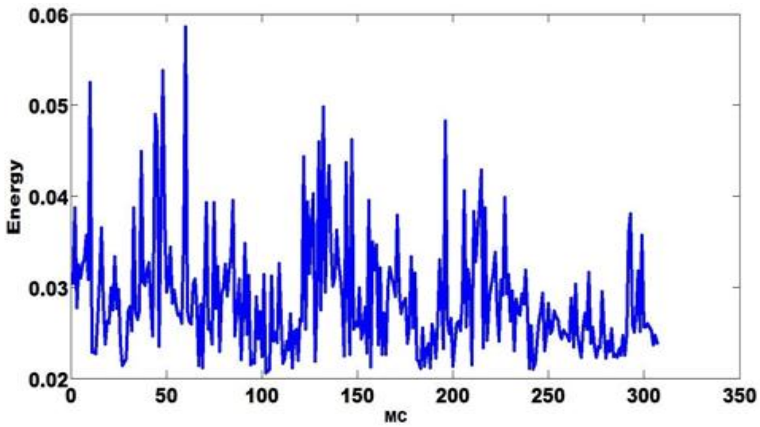
Step 4: Calculate the GLCM features such as Energy, Homogeneity, Contrast and Correlation.

Step 5: Compare the outputs of step 4 with all rows of MC template file.

Step 6: Find the rows in MC template file which is closer to the outputs of step 4 by Euclidean distance.

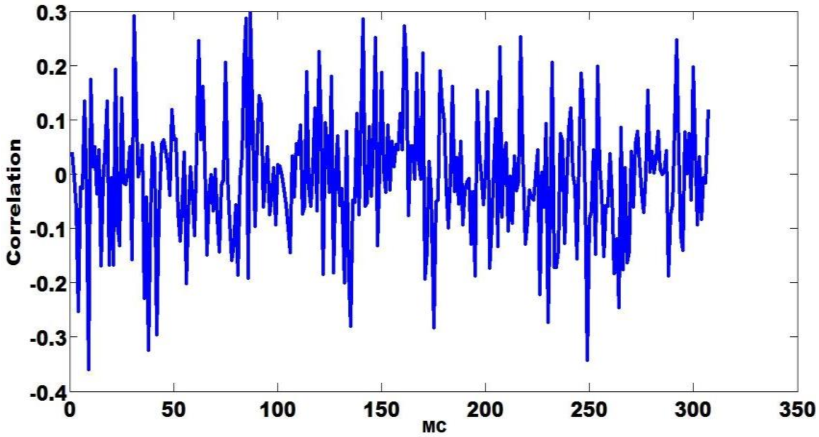
Step 7: If the output of step 7 < Matching threshold, then, a MC is identified

Step 8: Go to step 2 until the entire segmented black and white image is covered.



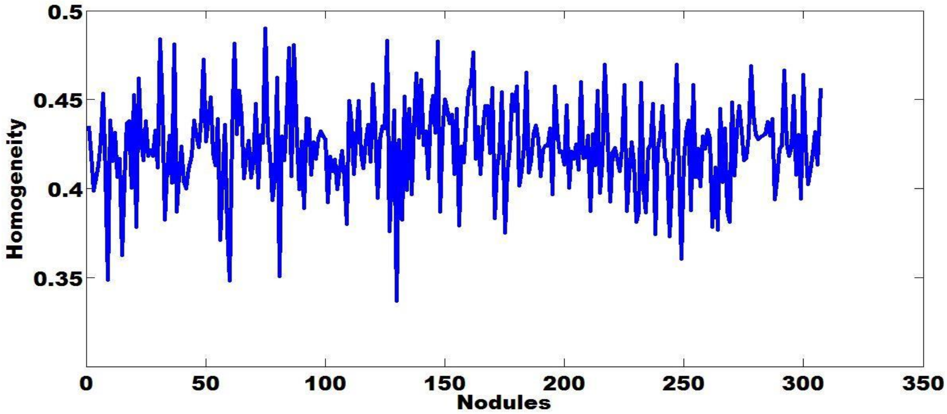
Energy Values for MC in Different mammogram images

The above figure presents the energy values calculated for MC of different mammogram images. Higher energy values occur when the gray level distribution has a constant or periodic form. The energy values are in the range of 0.02 till 0.06. It indicates that the MC is represented by a gradual change in its intensity values and it will be useful for the effective identification of different MC.



Correlation Values for MC in Different mammogram images

The above figure presents the correlation values calculated for MC of different mammogram images. Gray tone linear dependencies in the image are understood by the correlation process. The highest in correlation values indicates more the more similarity in matching. If the correlation is high, then template matching is easier



Homogeneity Values for MC in Different mammogram images

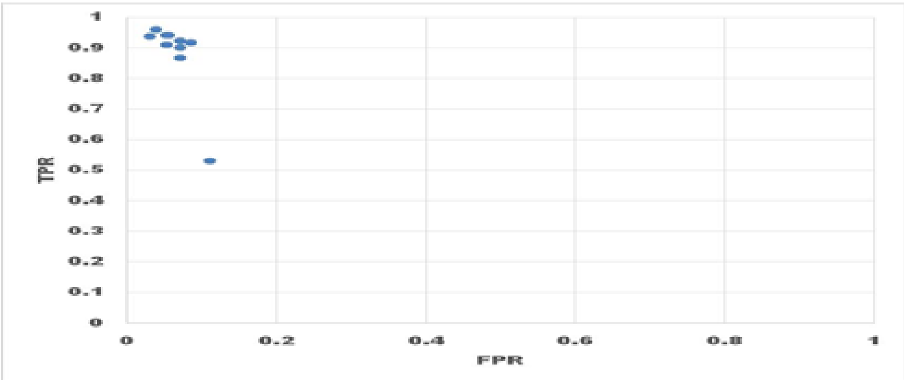
The above figure presents the homogeneity values calculated for MC of different mammogram images. It has a maximum value when all intensities in the images are same. Since the intensity values are different in the MC, the values of homogeneity are less than 0.5. Hence, MC detection becomes easier.

Performance Comparisons of Segmentaation Algorithms

The performance analysis of the proposed MC detection method has been carried out. For this process, images of patients are considered. All the images are segmented by wavelet, BPA, FL, FF and ESNN methods. This MC detection algorithm is applied for all the segmented images obtained from five segmentation algorithms. The algorithm checks the presence of how many false positive MC are detected in the segmented images which are actually not MC and the number of false negatives are obtained in the images that actually have MC.

To understand the consistency of the proposed algorithm for all the mammograms, a graph is plotted using Receiver operating characteristics (ROC) analysis. The ROC is plotted by calculating the true positive rate and false positive rate. For each mammogram, true positive rate and false positive rate are obtained. Based on the number of mammograms, equal no of points are plotted in the ROC. If the points are found to be above the diagonal, it is an indication of good performance of the proposed MC detection algorithm.

ROC Curve



ROC

The above graph presents the plot for FPR versus TPR. The points obtained are above the diagonal. Hence, the detection of MC by FL is within acceptable region.

Conclusions:

The following outputs are concluded.

1) The number of levels of decomposition of mammogram by wavelet affects the microcalcification (MC) identification accuracy.
2) The features extracted from the DB wavelet and coiflet wavelet is almost same.
3) The Back propagation algorithm takes sufficient number of iterations to learn the coefficients of the decomposed image. The MC identification accuracy depends on the type of input data. BPA should be trained with unique patterns as there will be lot of duplication of the patterns.
4) The performance of the FL in identifying the MC depends upon the number of rules used for training the FL.
5) To some extent noise is removed during decomposition and reconstruction of the mammogram.

Future Scope of the Work

The research work implemented in this thesis can be extended to new combinations of algorithms for detecting MC. The new combination can be combining ANN with genetic algorithm, ANN with particle swarm optimization.

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2. AbuBaker, A. (2015). Automatic microcalcification detection using wavelet transform. *International Journal of Computer Theory and Engineering, 7*(1), 40–45.
3. Ahirwar, A., & Jadon, R. S. (2011). Characterization of tumor region using SOM and neuro fuzzy techniques in digital mammography. *International Journal of Computer Science and Information Technology, 3*(1), 199–211.
4. Akila, K., Jayashree, L. S., & Vasuki, A. (2015). Mammographic image enhancement using indirect contrast enhancement techniques–a comparative study. *Procedia Computer Science, 47*, 255–261.
5. Al Mutaz, M. A., Dress, S., & Zaki, N. (2011). Detection of masses in digital mammogram using second order statistics and artificial neural network. *International Journal of Computer Science & Information Technology, 3*(3), 176–186.
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SYNTHESIS OF SILVER NANO PARTICLES

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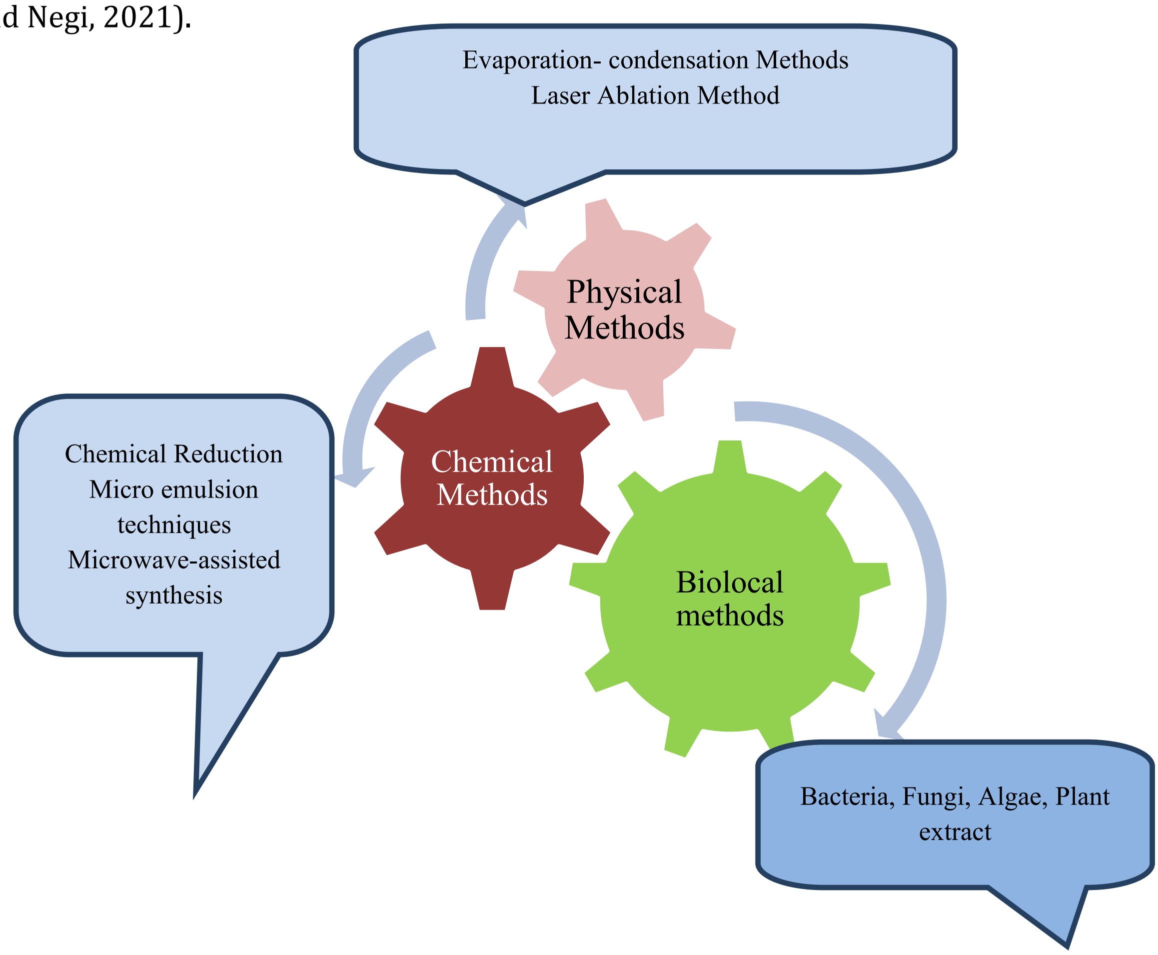
Introduction:

Nano particles are defined as substances measuring between 1 and 100 nanometres in size. In the last decade, a diverse array of nanoparticles (NPs) has seen extensive application worldwide. Numerous studies support the notion that nanotechnology is an expanding commercial field, largely attributed to the increasing variety of products that utilize nanoparticles (Mansoori *et al.,* 2008). The attributes of NPs are driven because of their physicochemical properties, and certain types are produced in significant quantities due to their exceptional qualities (Vali *et al.,* 2022). The discharge of nanoparticles into aquatic habitats occurs at several stages, encompassing their production, usage and the disposal of associated nano-wastes. (Ringwood *et al.,* 2010). In aquatic ecosystems, silver nanoparticles manifest in diverse forms, influenced by water's properties. Water in natural environments moves across land, traversing both surface and subterranean pathways until it arrives at estuarine and subsequently oceanic waters. During this transit, numerous physical transformations occur, which can either reduce the toxicity of the nanoparticles or exacerbate it. If these nanoparticles or their modified versions undergo agglomeration or self-aggregation within biological entities, they may pose serious health risks (Lapresta-Fernandez *et al.,* 2012). Nanoparticles exhibit toxicity that is significantly affected by factors such as their diminutive size, chemical composition, surface morphology, solubility, shape, and their propensity for agglomeration and aggregation. Nonspecific oxidative stress has emerged as a major concern associated with the toxicity induced by nanoparticles. Observations in fish and embryos exposed to these particles reveal various toxicological changes, particularly those related to oxidative stress, including lipid oxidation, programmed cell death (apoptosis), and alterations in gene expression (Mekkawy *et al.,* 2019). The potential risks posed by nanoparticles (NPs) within aquatic ecosystems can be effectively assessed by examining their bioavailability and toxicity to life which dwells in water (Nowack and Bucheli, 2007). At high concentrations, nano particles and their derivatives which are ionic may engage in interactions that could lead to detrimental effects on organisms which survive in water (Griffitt *et al.,* 2007; Xiang *et al.,* 2020). Among the most prevalent metal nanoparticles, silver nanoparticles (AgNPs) are known to induce several toxic effects in cellular systems, such as DNA damage, mitochondrial dysfunction, damage to membrane integrity and apoptosis. While the adverse effects are recognized, the mechanisms of their toxicity are not fully elucidated, with current understanding pointing to the involvement of reactive oxygen species (ROS) production, silver ion release, and lipid peroxidation of cell membranes (Xiang *et al.,* 2020).

Synthesis of Silver Nanoparticles

The environment friendly production of silver nanoparticles (AgNPs) is an uncomplicated and budget-friendly strategy that addresses the requirements of researchers and simultaneously mitigates the risk of environmental harm (Rogach, 2000). Various methods and approaches have been identified for the formation of silver nanoparticles (AgNPs), utilizing chemical, physical, photochemical and biological processes. Individually, every method offers distinct advantages and disadvantages, with same challenges related to cost, scalability and the uniformity of particle size and distribution. Nanoparticle synthesis via physical and photochemical methods often necessitates high temperatures, vacuum conditions, and expensive machinery (Vishwanath and Negi, 2021).

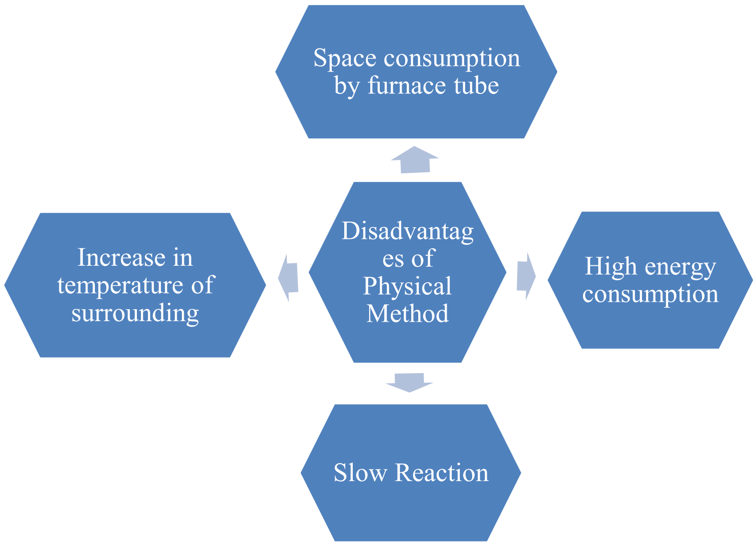


Physical Method

Among the physical techniques, evaporation-condensation and laser ablation stand out as primary methods. The evaporation-condensation technique involves the use of a tube furnace operating at atmospheric pressure for synthesis (Natsuki *et al.,* 2015).

The laser ablation technique executes with no usage of chemical reagents, contributing to efficiency of this method. Additionally, the lack of chemical solvents in this method renders it relatively eco-friendly. The size of nanoparticles can be regulated by varying the number of laser pulses used during synthesis. Silver nanoparticles with remarkable purity can be yielded using this technology. Notably, in antimicrobial applications, nanoparticles produced through laser ablation exhibit superior reactivity and antimicrobial efficacy compared to those synthesized through chemical methods. Therefore, these attributes suggest that laser ablation is efficient and environmentally sustainable approach (Vishwanath and Negi, 2021). Laser ablation has yet to be adopted on a larger scale for industrial purposes, largely due to its limited productivity. As a result, this method is not economically viable at this time (Sportelli *et al.,* 2018).

Although this method produces a significant quantity of nanoparticles, it is accompanied by several drawbacks:



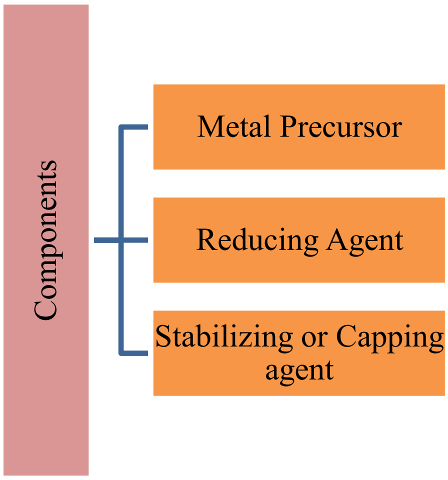
Disadvantages of Physical Method

Chemical Method

Chemical methods are primarily utilized for the fabrication of silver nanoparticles (AgNPs). These methods are well-established for producing pure and precisely defined nanoparticles, making them the preferred choice due to their ease of use and the minimal equipment required. These methods allow for the straightforward formation of AgNPs in solution, as they can be executed under mild and uncomplicated conditions. (Natsuki *et al.,* 2015).

Process of Synthesizing Silver Nano Particles

The synthesis of silver nanoparticles (AgNPs) in solution commonly incorporates three key elements:



The reduction of silver salts results in colloidal solutions, which are formed through a two-step process involving nucleation and subsequent growth. The findings indicate that the dimensions and morphology of the synthesized silver nanoparticles (AgNPs) are significantly influenced by these stages. Additionally, to achieve monodisperse AgNPs with a consistent size distribution, it is essential for all nuclei to form simultaneously (Natsuki *et al.,* 2015).

Chemical Reduction Method

Using reducing agents, the silver nitrate is reduced in the aqueous solution which is the most commonly suggested method among all chemical techniques and a stabilizing agent is also used to stabilize the silver nano particles. A range of reducing agents can be utilized, including citrate, ascorbate, borohydride, and hydrogen gas. In the realm of chemical synthesis, inorganic reducing agents like sodium citrate and sodium borohydride are commonly employed. Sodium citrate, characterized as a less effective reducing agent, tends to yield nanoparticles of a larger size than those formed by the more effective reducing agent, borohydride (Zewde *et al.,* 2016).Stabilizing agents typically consist of surfactants, ligands, or polymers with specific functional groups, such as polyvinyl pyrrolidone, elemental hydrogen, the polyol process, Tollens' reagent, N, N-dimethylformamide, poly (ethylene glycol)-block copolymers, hydrazine, ammonium formate, and polyethylene glycol to convert silver ions (Ag+) into nanoparticles (Dawadi *et al.,* 2021).

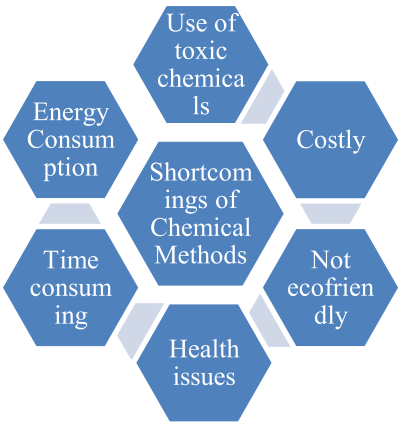
The size, shape, and structure of silver nanoparticles are determined by the molar ra tio of silver nitrate to the reducing agent, the starting concentration of the silver nitrate sol ution, and the concentration of the stabilizing agent. (Gudikandula and Maringanti, 2016).

Micro Emulsion Method

The Micro emulsion technique is considered a highly adaptable preparation method that enables the regulation of various particle properties, such as particle size control mechanisms, geometry, morphology, homogeneity, and surface area. Due to their outstanding properties, such as very low interfacial tension, extensive interfacial area, thermodynamic stability, and the capacity to dissolve immiscible liquids, micro emulsion techniques find numerous applications in the fields of chemistry and biology (Mubaddel *et al.,* 2017).

Microwave-Assisted Methods

The process of microwave synthesis utilizes adjustable-rate microwave radiation to reduce silver nanoparticles, as opposed to the standard heating techniques (Veerasamy *et al.,* 2011). The method facilitates a quicker reaction and yields a higher concentration of silver nanoparticles while maintaining the same temperature and exposure levels (Beyene *et al.,* 2017).



Drawbacks of Chemical Methods

Biological Methods

The biological method presents an appropriate and environmental friendly alternative to traditional chemical and physical synthesis techniques. Various living organisms, including plants, algae, microbes, fungi, and even animals, are used in the synthesis of nanoparticles. This is largely due to specific biomolecules, such as certain enzymes, that can be derived from these organisms, facilitating the in-situ reduction of silver ions (Ag^{+}) to produce silver nanoparticles. The preference for plants over microbes arises from the fact that photosynthesis is more economically viable and can be conveniently scaled for industrial purposes. One of the primary advantages of biological synthesis lies in the inherent safety of the process, as well as the high purity of the nanoparticles produced. This method minimizes the environmental impact associated with conventional synthesis approaches and ensures that the resulting nanoparticles are free from harmful contaminants increasing their suitability for a broad range of applications (Vishwanath and Negi, 2021).

Synthesis using Microorganisms

The microorganisms help in synthesizing nanoparticles, including silver and gold, has acquired considerable attention recently. Presently, bacteria and fungi are essential in the bioremediation of toxic metals through the reduction of metal ions. Currently, generation of metal nanoparticles via microbial processes is considered more viable than other methods. Studies have demonstrated that silver nanoparticles possess remarkable antimicrobial efficacy. Bacteria are utilized as biological agents for synthesizing silver nanoparticles, primarily because they are easy to handle and manipulate (Saeed et al, 2020).

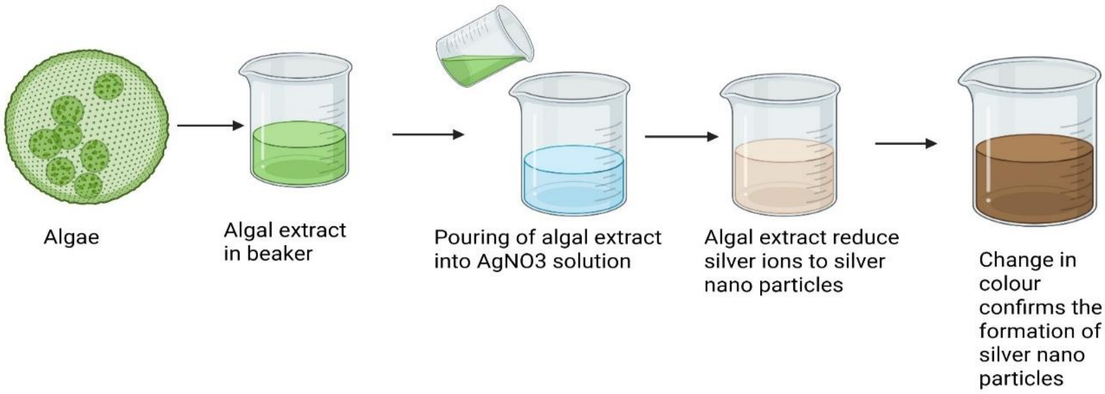
Pseudomonas stutzeri, in particular, demonstrates notable resistance to silver, which is linked to the intracellular formation of silver crystals that are roughly 200 nm in diameter and have a defined composition and structure (Beyene *et al.,* 2017). Bacteria serve as an effective means for the production of environmentally friendly and economically viable silver nanoparticles (AgNPs). The optimized culture of *Bacillus sp.* facilitated the rapid and efficient synthesis of these nanoparticles (Malarkodi *et al.,* 2013). It is established that bacteria can generate nanoparticles through two primary pathways: the first is through mechanisms that occur outside the cell, and the second takes place within the cellular environment (Alsamhary, 2020).

Srivastava *et al.* (2007) reported that *Pseudomonas aeruginosa* possesses the ability to biosynthesize various types of nanoparticles, including Pd, Ag, Rh, Ni, Fe, Co, Pt, and Li, within its cells without the need for stabilizing agents or external electrons. This finding prompted further studies to evaluate the nanoparticle production potential of a range of other bacteria, such as *Escherichia coli, Bacillus subtilis, Bacillus megaterium, Bacillus* *cereus, Pseudomonas aeruginosa, Klebsiella pneumoniae, Alteromonas,* and *Ochrobactrum* species, among others.

Synthesis of Silver Nano using Algae

The production of silver nanoparticles (Ag NPs) from various algal species constitutes over 50% of the existing research on metallic nanoparticles. These synthesized Ag NPs have potential applications in diverse fields, including jewellery, coatings, pharmaceutical delivery and healing of wounds. This is because of their exceptional physicochemical properties compared to bulk silver (Chan *et al.,* 2022). Brown algae are recognized for their ability to produce sterols, which serve as capping and reducing agents in nanoparticle synthesis. Notably, sterols like cholesterol, fecosterol and sulfated polysaccharides act as phycochemicals facilitating the biogenesis of nanoparticles. Additionally, functional groups including alginic acid, glucuronic acid, muramic acid, and vinyl derivatives play an important role in the mechanisms of synthesis (Kumar *et al.,* 2011). Prasad *et al.* 2013 demonstrated that silver nanoparticles can be produced using the Australasian brown marine algae *Cystophora moniliformis* and *Turbinaria conoides*.

It has been proposed that *Turbinaria* species, namely *T. ornate* and *T. conoides,* can produce effective reducing agents for the synthesis of nanoparticles. The reducing agents identified include amines, carbonyl compounds, free hydroxyl groups, various organic moieties, and polyamines, which are integral to the reduction of silver salt precursor solutions (Khalil *et al.,* 2014; Kumar *et al.,* 2015). The process of reducing silver nitrate to aqueous silver metal ions resulted in the formation of silver nanoparticles, facilitated by the extract of the red algae *H. musciformis* (Chan *et al.,* 2022). *Pithophore oedogoni* has been effectively investigated for the generation of silver nanoparticles, achieving a mean diameter of 34.03 nm. On the other hand, the extract from *Caulerpa serrulata* was found to successfully reduce silver ions to form spherical silver nanoparticles with a size of 10 ± 2 nm (Aboelfetoh *et al.,* 2017). Within microalgae cells, polyphosphates are located internally, while polysaccharides are situated externally. Both of these substances can effectively capture metal ions that are present in the environment, leading to their reduction. This reduction process is similar to that of carboxyl groups on the cell surface, which also engage in interactions with metal ions (Chan *et al.,* 2022).



Process of formation of silver nano particles using algal extract

Plant Extract Based Synthesis of Silver Nano Particles

The formation of silver nanoparticles often involves usage of biomolecules derived from plant extracts. This approach to nanoparticle synthesis is known as "phytosynthesis." To facilitate the synthesis of silver nanoparticles using plants, an aqueous extract is obtained from the leaves, roots, or stems of the plants, followed by the addition of an aqueous solution containing a silver salt (Guilger and Lima, 2019). This approach closely parallels conventional chemical methods, but utilizes non-toxic reagents sourced from plants. Furthermore, the synthesis requires fewer reagents since plant extracts act as reducing as well as stabilizing agents. This approach closely parallels conventional chemical methods, but utilizes non-toxic reagents sourced from plants. Furthermore, the synthesis requires fewer reagents since plant extracts act as both reducing and stabilizing agents. The reaction generally occurs in a single step, demonstrating high efficiency and rapidity (Vishwanath and Negi, 2021). The presence of alkaloids, flavonoids, triterpenoids, phenolic compounds, carotenoids, steroids, and ketones in plant extract plays a significant role in facilitating the reduction process, enabling them to bind with metals, reduce metal salts and maintain stability against agglomeration (Lagashetty *et al.,* 2019).

Conclusion:

Nano technology is extending day by day diversifying the use of metal nano particles in different fields. Synthesis of silver nano particles include various methods out of which biological methods is most effective. The eco - friendly approach of green synthesis of silver nano makes them efficient to be utilised for different purposes in various fields. Phytochemicals found in plant extracts and reducing agents from micro- organisms help in reduction as well as stabilization process of silver ions into silver nano particles.

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THE CHEMISTRY OF ACID RAIN: CAUSES AND ITS IMPACT ON HUMAN AND ENVIRONMENT

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Abstract:

Acid rain is made up of highly acidic water droplets due to air emissions, most specifically the disproportionate levels of sulphur and nitrogen emitted by vehicles and manufacturing processes. It is often called acid rain as this concept contains many types of acidic precipitation. The acidic deposition takes place in two ways: wet and dry. Wet deposition is any form of precipitation which removes acids from the atmosphere and places them on the surface of the earth. In the absence of precipitation, dry deposition of polluting particles and gases sticks to the ground through dust and smoke. Acid Rain is a significant environmental issue that has garnered attention for its detrimental impacts on ecosystems, human health, and infrastructure. As a key topic in environmental science; it is crucial for environmental conservation and sustainable development. This book chapter aims to discuss on acid rain in detail, including its meaning, causes, processes involved, impacts, and related concepts such as acid deposition.

Keywords: Aquatic Animals, Chemical Climatology, Acid-Producing, Mobilize Toxins.

Introduction:

The corrosive effect of polluted, acidic city air on limestone and marble was noted in the 17th century by John Evelyn, who remarked upon the poor condition of the Arundel marbles.[1] Since the Industrial Revolution, emissions of sulphur dioxide and nitrogen oxides into the atmosphere have increased.[2,3] The term acid rain was coined in 1852 by Scottish chemist Robert Angus Smith, according to the Royal Society of Chemistry,[4] which calls him the "father of acid rain." Smith decided on the term while examining rainwater chemistry near industrial cities in England and Scotland. He wrote about his findings in 1872 in the book "Air and Rain: The Beginnings of a Chemical Climatology". In the 1950s, scientists in the United States started studying the phenomenon, and in the 1960s and early 1970s, acid rain became recognized as a regional environmental issue that affected Western Europe and eastern North America.

Acid rain, or acid deposition, is a broad term that includes any form of precipitation that contains acidic components, such as sulphuric acid or nitric acid, according to the Environmental Protection Agency (EPA). The precipitation is not necessarily wet or liquid; the definition includes dust, gasses, rain, snow, fog and hail. The type of acid rain that contains water is called wet deposition. Acid rain formed with dust or gasses is called dry deposition.

After an asteroid supposedly wiped out the dinosaurs 65.5 million years ago, sulphur trioxide was blasted into the air. When it hit the air, it turned into sulphuric acid, generating a downpour of acid rain, according to a paper published in 2014 in the journal Nature Geosciences, even before that, over 4 billion years ago, it is suspected that the air may have had 10.000 times as much carbon dioxide as today. Geologists from the University of Wisconsin-Madison backed up this theory be studying rocks and publishing the results in a 2008 issue of the journal Earth and Planetary Science Letters. "At I those levels of carbon dioxide, you would have had vicious acid rain and intense greenhouse effects. That is a condition that will dissolve rocks," said study team member John Valley. [Early Earth Marred by Acid Rain]

Public awareness of acid rain in the US increased in the 1970s after The New York Times published reports from the Hubbard Brook Experimental Porest in New Hampshire of the harmful environmental effects that result from it.[5,6] The problem of acid rain has not only increased with population and industrial growth, but has become more widespread. The use of tall smokestacks to reduce local pollution has contributed to the spread of acid rain by releasing gases into regional atmospheric circulation.[7,8] Often deposition occurs a considerable distance downwind of the emissions, with mountainous regions tending to receive the greatest deposition (because of their higher rainfall). An example of this effect is the low pH of rain which falls in Scandinavia.

Causes of Acid Rain:

There are two types of causes for the acid rain or polluted rain one is natural phenomenon or natural activity and another is manmade activity.

Natural Activity:

Different types of natural disasters are responsible for acid rain. The principal natural phenomena that contribute acid-producing gases to the atmosphere are emissions from volcanoes. They create extremely high amounts of acid rain and fog, with acidity as high as a pH of 2, clearing an area of any vegetation and frequently causing irritation to the eyes and lungs of inhabitants in nearby settlements.

Acid-producing gasses are also created by biological processes that occur on the land, in wetlands, and in the oceans. The major biological source of sulphur compounds is diethyl sulphide. Nitric acid in rainwater is an important source of fixed nitrogen for plant life, and is also produced by electrical activity in the atmosphere such as lightning.[9] Soils of coniferous forests are naturally very acidic due to the shedding of needles, and the results of this phenomenon should not be confused with acid rain.

Burning of forest also produced huge amount of carbon dioxide and carbon monoxide which polluted the air and sometimes at the time of rain it reacts with water droplets to produce acid rain.

Manmade Activity:

The main cause for acid rain is due to human activity. For our smooth, comfortable and luxurious life style we damage continuously the environmental e balance and different gaseous cycle of the environment. The principal cause of acid rain is sulphur and nitrogen compounds from human sources, such as electricity generation. Factories, and motor vehicles. Electrical power generation using coal is among the greatest contributors to gaseous pollution responsible for acidic rain. The oil refineries, different types of factories, motor vehicles all are produces different types of poisonous gases like SO_2, CO, NO_2, CO, H_2S etc. The gases can be carried hundreds of kilometres in the atmosphere before they are converted to acids and deposited. In the past, factories had short funnels to let out smoke but this caused many problems locally; thus, factories now have taller smoke funnels. However, dispersal from these taller stacks causes pollutants to be carried farther, causing widespread ecological damage.

Another reason for acid rain may be the population. Due to drastically increasing population across the World, to fulfilment of their basic needs and growing demands they rapidly cut the forest for establishment of their house, factories, etc and vehicles for transportation increases drastically. Due to increasing the number of factories, vehicles, etc number of poisonous gases mainly SO_2, and NO_2 increases in atmosphere and probability of acid rain increases.

Chemical Processes:

During the acid rain the following reactions are happened in two different phases. Combustion of fuels produces sulphur dioxide and nitric oxides. They are converted into sulphuric acid and nitric acid. [10]

Gas Phase Chemistry:

In the gas phase in the presence of water sulphur dioxide is converted to sulphuric acid; and nitrogen dioxide converted to nitric acid.[11]

$$SO_2 + H_2O \rightarrow H_2SO_4 \longleftrightarrow H^+ + HSO_4 \longleftrightarrow 2H^+ + SO_4^2$$

$$NO_2 + H_2O \rightarrow HNO_3 \longleftrightarrow H^+ + NO_3$$

Chemistry in Cloud Droplets:

When clouds are present, the loss rate of SO_2 is faster than can be explained bt gas phase chemistry alone. This is due to reactions in the liquid water droplets.

Hydrolysis

Sulphur dioxide dissolves in water and then, like carbon dioxide, hydrolyses in a series of equilibrium reactions:

$$SO_2\,(g) + H_2O \rightleftharpoons SO_2.H_2O \qquad NO_2\,(g) + H_2O \rightleftharpoons NO_2.H_2O$$

$$SO_2.H_2O \rightleftharpoons H^{\oplus} + HSO_3^{\ominus} \qquad NO_2.H_2O \rightleftharpoons H^{\oplus} + HNO_3$$

$$HSO_3^{\ominus} \rightleftharpoons H^{\oplus} + SO_3^{2-} \qquad HNO3 \rightleftharpoons H^{\oplus} + NO_3^{-}$$

Oxidation

There are a large number of aqueous reactions that oxidize sulphur from S(IV) to S(VI), leading to the formation of sulphuric acid. The most important oxidation reactions are with ozone, hydrogen peroxide and oxygen (reactions with oxygen are catalyzed by iron and manganese in the cloud droplets).[11]

Deposition of Acid:

Acids are deposited on the Earth surface in two phases as wet deposition and dry deposition.

Wet Deposition:

Wet deposition of acids occurs when any form of precipitation (rain, snow, and so on.) removes acids from the atmosphere and delivers it to the Earth's surface. This can result from the deposition of acids produced in the raindrops (see aqueous phase chemistry above) or by the precipitation removing the acids either in clouds or below clouds. Wet removal of both gases and aerosols are both of importance for wet deposition.

Dry Deposition:

Acid deposition also occurs via dry deposition in the absence of precipitation. This can be responsible for as much as 20 to 60% of total acid deposition.[12] This occurs when particles and gases stick to the ground, plants or other surfaces.

Effects:

Acid rain has been shown to have adverse impacts on forests, freshwaters and soils, killing insect and aquatic life-forms as well as causing damage to buildings and having impacts on human health.

Surface Waters and Aquatic Animals:

Not all fish, shellfish, or the insects that they eat can tolerate the same amount of acids; e.g., frogs can tolerate water that is more acidic (i.e., has a lower pH) than trout. Both the lower pH and higher aluminium concentrations in surface water that occur as a result of acid rain can cause damage to fish and other aquatic animals. At pH lower than 5 most fish eggs will not hatch and lower pH can kill adult fish. As lakes and rivers become more acidic biodiversity is reduced. Acid rain has eliminated insect life and some fish species, including the brook trout in some lakes, streams, and creeks in geographically sensitive areas, such as the Adirondack Mountains of the United States.[13] However, the extent to which acid rain contributes directly or indirectly via runoff from the catchment to lake and river acidity (i.e., depending on characteristics of the surrounding watershed) is variable. The United States Environmental Protection Agency's (EPA) website states: "Of the lakes and streams surveyed, acid rain caused acidity in 75% of the acidic lakes and about 50% of the acidic streams".[13] Lakes hosted by silicate basement rocks are more acidic than lakes within limestone or other basement rocks with a carbonate composition (i.e. marble) due to buffering effects by carbonate minerals, even with the same amount of acid rain.[14]

Soils:

Soil biology and chemistry can be seriously damaged by acid rain. Some microbes are unable to tolerate changes to low pH and are killed.[15] The enzymes of these microbes are denatured (changed in shape so they no longer function) by the acid. The hydronium ions of acid rain also mobilize toxins, such as aluminium, and leach away essential nutrients and minerals such as magnesium. 16

$$2\ H^+\ (aq) + Mg^{2+}\ (clay) \rightleftharpoons 2\ H^+\ (clay) + Mg^{2+}\ (aq)$$

Soil chemistry can be dramatically changed when base cations, such as calcium and magnesium, are leached by acid rain thereby affecting sensitive species, such as sugar maple (Acer saccharin).[17,18] Due to increasing the acidity of the soil fertility will be decreases and production of the crop adversely affected.

Forests and other Vegetation:

Acid rain can have severe effects on vegetation. Adverse effect may be indirectly related to acid rain, like the acid's effects on soil (see above) or high concentration of gaseous precursors to acid rain. High altitude forests are especially vulnerable as they are often surrounded by clouds and fog which are more acidic than rain.

Other plants can also be damaged by acid rain, but the effect on food crops is minimized by the application of lime and fertilizers to replace lost nutrients. In cultivated areas, limestone may also be added to increase the ability of the soil to keep the pH stable, but this tactic is largely unusable in the case of wilderness lands. When calcium is leached from the needles of red spruce, these trees become less cold tolerant and exhibit winter injury and even death.[19,20]

Ocean Acidification:

Acid rain has a much less harmful effect on the oceans. Acid rain can cause the ocean's pH to fall, making it more difficult for different coastal species to create their exoskeletons that they need to survive. These coastal species link together as part of the ocean's food chain and without them being a source for other marine life to feed off of more marine life will die.[21]

Coral's limestone skeletal is sensitive to pH drop, because the calcium carbonate, core component of the limestone dissolves in acidic (low pH) solutions.

Human Health Effects:

Acid rain does not directly affect human health. The acid in the rainwater is too dilute to have direct rain (sulphur dioxide and nitrogen oxides) o have an adverse effects. The particulates responsible for acid adverse effect. Increased amounts of fine particulate matter in the air contribute to heart and lung problems including asthma and bronchitis.[22]

Other Adverse Effects:

Effect of Acid Rain on Statues:

Now a day's due to severe environmental pollution the amount of SO_2, and NO_2 increases and due to increasing amount of these gases the probability of acid amount increases with the rain water. For this reason different types of valuable statues across the world and Tajmahal also decreases their glossiness

Acid Rain and Weathering:

Acid rain can damage buildings, historic monuments, and statues, especially those made of rocks, such as limestone and marble, that contain large amounts of calcium carbonate. Acids in the rain react with the calcium compounds in the stones to create gypsum, which then flakes off.

$$CaCO_3\,(s) + H_2SO_4\,(aq) \rightleftharpoons CaSO_4(S) + CO_2\,(g) + H_2O\,(l)$$

The effects of this are commonly seen on old gravestones, where acid rain can cause the inscriptions to become completely illegible. Acid rain also increases the corrosion rate of metals, in particular iron, steel, copper and bronze.[23,24]

Affected Areas:

Places significantly impacted by acid rain around the globe include most of eastern Europe from Poland northward into Scandinavia,[25] the eastern third of the United States,26 and southeastern Canada. Other affected areas include the southeastern coast of China and Taiwan.27

Prevention Method:

Technical Solutions:

Many coal-firing power stations use flue-gas desulfurization (FGD) to remove sulphur-containing gases from their stack gases. For a typical coal-fired power station, FGD will remove 95% or more of the SO, in the flue gases. An example of FGD is the wet scrubber which is commonly used. A wet scrubber is basically a reaction tower equipped with a fan that extracts hot smoke stack gases from a power plant into the tower, Lime or limestone in slurry form is also iniected into the tower to mix with the stack gases and combine with the sulphur dioxide present. The calcium carbonate of the limestone produces pH- neutral calcium sulphate that is physically removed from the scrubber. That is, the scrubber turns sulfur pollution into industrial sulphates.

In some areas the sulphates are sold to chemical companies as gypsum when the purity of calcium sulphate is high. In others, they are placed in landfill. The effects of acid rain can last for generations, as the effects of pH level change can stimulate the continued leaching of undesirable chemicals into otherwise pristine water sources, killing off vulnerable insect and fish species and blocking efforts to restore native life.

Fluidized bed combustion also reduces the amount of sulphur emitted by power production. Vehicle emissions control reduces emissions of nitrogen oxides from motor vehicles.

International Treaties:

International treaties on the long-range transport of atmospheric pollutants have been agreed for example, the 1985 Helsinki Protocol on the reduction of sulphur emissions under the convention on long- range transboundary Air Pollution. Canada and the US signed the Air Quality Agreement in 1991. Most European countries and Canada have signed the treaties.

Emissions Trading:

In this regulatory scheme, every current polluting facility is given or may purchase on an open market an emissions allowance for each unit of a designated pollutant it emits. Operators can then install pollution control equipment, and sell portions of their emissions allowances they no longer need for their own operations, thereby recovering some of the capital cost of their investment in such equipment. The intention is to give operators economic incentives to install pollution controls.

The first emissions trading market was established in the United States by enactment of the Clean Air Act Amendments of 1990.[28] The overall goal of the Acid Rain Program established by the Act[29] is to achieve significant environmental and public health benefits through reductions in emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_2), the primary causes of acid rain. To achieve this goal at the lowest cost to society, the program employs both regulatory and market based approaches for controlling air pollution.

Conclusions:

Acid rain is a Sevier problem across the World. Now a day's it is a growing concern to the scientist to resolve the problem. It is required to enhance the consciousness among the people in all over World. We need to pull the chain to the pollution because this is the main reason for acid rain.

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ADVANCEMENTS AND CHALLENGES IN SPACE FOOD TECHNOLOGY: ENSURING SAFETY, NUTRITION, AND SHELF LIFE FOR ASTRONAUTS

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Abstract:

Despite significant progress, space food technology still faces limitations, particularly in producing food that is both easily rehydratable and digestible, especially given the scarcity of water in space. Critical attributes of space food include safety, stability, palatability, nutrition, efficiency, variety, reliability, and compatibility with space-specific appliances. Technologies originally developed to prevent foodborne illnesses in astronauts—such as canning and HACCP protocols—are now integral to the global food industry. Space food is preserved using methods like thermal processing, irradiation, freeze-drying, and the use of shelf-stable and natural food products. However, a major limitation is the relatively short shelf life of space food, typically up to 18 months. This chapter explores the technological advancements, processing methods, and challenges of developing safe and nutritious food systems for space missions.

Keywords: Space Food Technology, Astronaut Nutrition, Food Processing Methods, Microbial Inactivation, Shelf-Life Stability

Introduction:

Space food refers to specially designed and processed food products tailored for human consumption in outer space. In microgravity conditions, food must be compact, lightweight, easy to consume, and resistant to contamination, degradation, and the effects of radiation and low atmospheric pressure. The development of nutritionally balanced space meals plays a crucial role in ensuring astronaut health and cognitive function, both essential for the success of long-duration missions. Additionally, the food must be resistant to contamination and degradation caused by exposure to radiation, low atmospheric pressure, and temperature fluctuations (Douglas *et al.,* 2021).

The constraints of water, storage, preparation time, and limited onboard resources restrict the variety of food available. As a result, food systems primarily rely on shelf-stable, single-serving meals preserved by freeze-drying, thermostabilizing, or irradiation. Proper preservation and innovative packaging methods help maintain the safety, palatability, and nutritional adequacy of space food.

1. Evolution of Space Food

The evolution of space food is closely tied to the progression of human space exploration, from the early Mercury missions to the long-duration stays aboard the International Space Station (ISS), and future aspirations for Mars missions. During the 1960s, the primary concern was to provide basic nutrition and caloric intake in a zero-gravity environment. The first foods were squeezed from aluminum tubes, such as pureed applesauce or meat paste, and consumed like toothpaste. These were quickly found to be unpalatable and difficult to use effectively (Smith & Perchonok, 2020).

The Gemini missions introduced bite-sized, freeze-dried cubes that were easier to manage but lacked flavor and variety. Astronauts frequently complained about the taste and monotony, prompting NASA to improve both food composition and packaging. By the Apollo era, food was being packaged in lightweight, easy-to-open vacuum pouches. More importantly, food items were thermostabilized or freeze-dried and could be rehydrated with warm water, increasing their appeal and ease of use. These foods included scrambled eggs, rehydratable soups, and small canned entrees (Perchonok & Cooper, 2019).

Skylab marked a turning point in space food evolution. With more room and a galley on board, astronauts had access to over 70 different food items, including some that could be refrigerated or heated. Food trays with magnetic utensils allowed for semi-normal dining experiences. This was the first time meals were eaten together, improving psychological morale. By the Shuttle and ISS eras, space food had become more diverse and sophisticated. Meal systems included vacuum-sealed packages, rehydratable pouches, thermostabilized foods, irradiated meats, and some natural form items like nuts and dried fruits. Advanced packaging materials helped to extend shelf life while reducing mass and volume (NASA, 2020).

Currently, ISS crews receive periodic fresh produce from Earth via resupply missions, and the food menu rotates regularly to include international dishes from U.S., Russian, European, and Japanese space programs. There is now a stronger emphasis on nutritional adequacy, sensory satisfaction, and variety, especially for missions exceeding six months. Research for future long-duration missions, such as a crewed mission to Mars, focuses on bioregenerative food systems, hydroponics, and food production in space habitats to reduce reliance on resupply (Tang *et al.,* 2021).

Overall, the evolution of space food has transitioned from simple nutrition delivery to a complex, multidisciplinary system addressing health, psychology, culture, and technology. Each era brought not just enhancements in food composition but also advances in packaging, preparation methods, and the integration of nutritional science, making space food one of the most unique and challenging areas of food technology research.

2. Classification of Space Food

Space food is generally classified into six major categories based on the type of preservation, preparation requirements, and storage characteristics. These categories were developed to meet the diverse needs of astronauts in space, where ease of handling, safety, and nutritional balance are paramount (Kloeris & Perchonok, 2023).

2.1 Rehydratable Food: These are freeze-dried or dehydrated foods that require the addition of water before consumption. Rehydration is performed using cold or hot water depending on the dish. Common examples include scrambled eggs, soups, cereals, and pasta. These foods are lightweight, compact, and have a long shelf life, making them ideal for space missions.

2.2 Thermostabilized Food: Thermostabilized foods are heat-processed and sealed in flexible pouches or cans to destroy harmful microorganisms and enzymes. This method extends shelf life while preserving taste and texture. Examples include stews, rice dishes, and fruit cocktails. These meals can be eaten cold or warmed using special onboard food warmers.

2.3 Irradiated Food: These foods, mainly high-protein items like beefsteak or turkey, are exposed to ionizing radiation to ensure sterility without significantly affecting texture or taste. Irradiated foods are vacuum-packed in foil pouches and are ready-to-eat, making them convenient for zero-gravity environments (FAO, 2021).

2.4 Natural Form Food: Natural form foods are those that require no special processing for space travel. They include foods such as nuts, granola bars, crackers, and dried fruits. These are included in the space menu for their palatability, ease of handling, and contribution to variety and morale.

2.5 Fresh Food: Fresh fruits, vegetables, and breads are supplied occasionally through resupply missions. These foods help improve dietary variety and are important for psychological well-being. However, their perishability limits their availability, and they must be consumed early in the mission.

2.6 Beverages: Beverage options include tea, coffee, fruit juices, and electrolyte drinks. These are often provided in powdered form and require rehydration. They are packaged in special drink pouches equipped with straws to allow easy consumption in microgravity conditions.

This classification system enables mission planners and nutritionists to design balanced, practical, and appealing menus for astronauts, while addressing the challenges posed by microgravity, limited storage, and long-duration travel.

3. Challenges and Design Considerations

The development of space food is a complex process that must address a variety of engineering, biological, and psychological challenges. As human missions become longer and more distant, the ability to provide safe, nutritious, and appealing food systems becomes increasingly critical. Several core challenges and design considerations have shaped the current and future direction of space food technology.

3.1. Safety and Microbial Stability: Food safety is a top priority in space missions due to the confined nature of spacecraft and the impossibility of addressing foodborne illness in orbit. All space foods must be free from harmful pathogens, and packaging must prevent microbial contamination during storage and handling. Techniques such as irradiation, thermal processing, and vacuum sealing are employed to ensure microbial stability (Douglas *et al.,* 2022). Additionally, cleanroom environments and sterilization of packaging materials further mitigate risks.

3.2. Nutritional Adequacy: Spaceflight induces physiological changes including bone demineralization, fluid redistribution, and reduced immune function. Thus, space food must not only meet caloric requirements but also supply adequate micronutrients—particularly calcium, potassium, vitamin D, and antioxidants—to counteract the effects of microgravity (Smith & Perchonok, 2020). Extended missions necessitate highly stable nutrients that do not degrade over time. However, vitamins such as C and B1 are known to decline during long-term storage, prompting research into improved formulations and fortification techniques.

3.3. Palatability and Acceptability: In microgravity, fluid shifts dull the sense of taste and smell, making food seem bland. Thus, enhancing flavor without compromising safety is a priority. Spices, condiments, and varied textures help maintain appetite and food intake. Palatability also contributes to the psychological well-being of astronauts, helping to reduce stress, maintain morale, and support overall mental health during long-duration missions (Kloeris & Perchonok, 2023).

3.4. Packaging and Waste Management: Packaging must be lightweight, durable, and easy to use in microgravity. It must also protect food from moisture, oxygen, and radiation. Packaging materials must minimize waste, which is critical given the confined storage space and limited disposal options onboard spacecraft. Innovations include multilayered laminates, resealable containers, and biodegradable materials to support sustainability goals (Kloeris, 2021).

3.5. Preparation and Usability: Space food should be easy to prepare and consume, particularly in the limited space and low-gravity conditions of spacecraft. This means meals must be single-serving, easy to open, and require minimal utensils. For example, beverages are consumed through straws attached to specially designed pouches. Heating systems must also be compact and efficient, with some meals designed for ambient consumption to reduce reliance on thermal equipment (NASA, 2020).

3.6. Shelf Life and Storage: Shelf life is a limiting factor, especially for missions lasting over a year. Most current space foods have a shelf life of 18–24 months. Preservation methods must not only extend storage stability but also retain nutrient value and sensory quality. New technologies, such as microwave-assisted thermal sterilization (MATS) and high-pressure processing (HPP), are being explored to address this issue while maintaining nutritional and sensory integrity (Perchonok & Cooper, 2019).

3.7. System Integration: Space food systems must integrate seamlessly with environmental control, life support, and waste management systems. For future deep-space missions, closed-loop or bioregenerative food systems may be necessary. These would involve growing food onboard and recycling waste to support sustainability and reduce reliance on Earth-based resupply (Tang *et al.,* 2021).

Overall, addressing these challenges requires a multidisciplinary approach combining food science, nutrition, engineering, microbiology, and psychology. As missions extend beyond low-Earth orbit, the role of food systems will expand from mere sustenance to a vital component of crew health, performance, and survival.

Space food systems must meet stringent criteria for safety, palatability, nutrition, and resource efficiency. Food safety is assured through multiple preservation methods and microbiological testing (Douglas *et al.,* 2021). Palatability is essential to ensure astronauts consume sufficient calories to meet energy demands, as taste perception is often dulled in space due to fluid shifts (Heer *et al.,* 2015).

A balanced diet is critical to prevent deficiencies in essential micronutrients such as vitamin D, calcium, and potassium. These nutrients often degrade during extended storage, requiring careful planning and supplementation (Cooper *et al.,* 2011). Resource constraints onboard require food systems that generate minimal waste and require limited water and energy input. Usability and reliability of packaging and appliances are also vital, with all systems tested under simulated spaceflight conditions (Taylor *et al.,* 2020).

4. Impact on Global Food Safety Standards

The rigorous standards developed for space food have not only improved astronaut nutrition but also had a profound impact on global food safety systems. One of the most influential contributions is the introduction of the Hazard Analysis and Critical Control Point (HACCP) system. Originally implemented by NASA in collaboration with Pillsbury and the U.S. Army Natick Laboratories during the 1960s to ensure zero-defect foods for space missions, HACCP has since become a global benchmark for food safety management systems (Perchonok & Bourland, 2021).

HACCP's science-based approach emphasizes prevention by identifying and controlling potential biological, chemical, and physical hazards in food production processes. Its principles have since been adopted by global regulatory agencies such as the World Health Organization (WHO), Food and Agriculture Organization (FAO), and the U.S. Food and Drug Administration (FDA) as foundational to modern food safety regulations.

Beyond HACCP, the strict requirements for thermal processing, packaging integrity, microbial testing, and shelf-life validation in space food systems have influenced commercial food production, especially in sectors such as ready-to-eat meals, retort packaging, and military rations. NASA’s cleanroom protocols and traceability systems inspired industry-wide adoption of Good Manufacturing Practices (GMPs), sanitation standard operating procedures (SSOPs), and hazard tracking in supply chains.

The innovation and diligence required to protect astronauts from foodborne illness under extreme conditions have fostered improvements in packaging technology, cold-chain logistics, and sterilization methods used in both commercial and humanitarian food systems. These improvements have increased food security, reduced spoilage, and helped develop sustainable packaging solutions for terrestrial use.

5. Space Food Packaging: History and Innovation

The evolution of space food packaging has closely followed advancements in materials science and the increasing complexity of space missions. In the early Mercury and Gemini programs, food was packaged in collapsible aluminum tubes and bite-sized cubes wrapped in gelatin to reduce crumbs in microgravity. While functional, these packages were limited in both usability and food preservation (Perchonok & Bourland, 2021).

During the Apollo missions, NASA introduced vacuum-sealed, lightweight polymer pouches and metal cans capable of withstanding higher pressures and temperatures. These innovations allowed for thermostabilized and freeze-dried foods that could be rehydrated onboard using the spacecraft’s water supply. Packaging incorporated features like color-coded labels, Velcro attachments, and tear notches to assist astronauts in handling food without gravity (Smith & Perchonok, 2020).

The Shuttle era marked a significant leap with the introduction of multilayer co-extruded films designed for durability, low permeability, and heat resistance. These films combined layers of polyester, aluminum foil, and polypropylene to ensure moisture and oxygen barriers, extending shelf life and reducing microbial contamination (Kloeris & Perchonok, 2023).

For the International Space Station (ISS), packaging systems became more advanced, supporting storage for up to 18–24 months and minimizing mass and volume. Innovations included vacuum-packaged beverages in laminate pouches with built-in straw ports and resealable snack bags for dried goods. The design also took into account trash reduction, with compressible and flame-resistant materials (NASA, 2022).

Modern research is focused on smart packaging technologies that monitor temperature, microbial activity, or integrity through embedded sensors and indicator strips. Materials such as bacterial cellulose, biopolymers, and radiation-resistant coatings are under investigation for long-duration missions beyond Earth orbit. Moreover, there is a push toward developing biodegradable, edible, or reusable packaging systems to minimize waste during planetary exploration missions (Tang *et al.,* 2021).

The future of space packaging lies in integrating data-tracking, preservation functionality, and sustainability into a single compact design. As human spaceflight moves toward Mars and beyond, packaging systems will need to be lighter, safer, and more intelligent than ever before.

6. Food Processing and Preservation Techniques

The processing and preservation of space food are critical to ensure safety, stability, nutrition, and palatability during extended missions. Due to the lack of refrigeration, limited water, and harsh environmental factors such as microgravity and radiation, specialized methods have been developed and continuously improved. These techniques are designed to maintain food integrity while adhering to spacecraft constraints related to volume, mass, and power usage.

6.1. Freeze-Drying (Lyophilization): Freeze-drying is the most commonly used preservation method for space food. It involves freezing the food and then reducing the surrounding pressure to allow the frozen water to sublimate directly from solid to gas. This method significantly reduces food weight while preserving most of the nutritional value, flavor, and texture. Freeze-dried meals are rehydrated with hot or cold water onboard before consumption. They also have a long shelf life, typically up to five years under controlled conditions (Cooper *et al.,* 2017).

6.2. Thermostabilization: Thermostabilized foods are processed by heating them to high temperatures to destroy spoilage organisms and pathogens, then sealing them in metal cans or flexible retort pouches. This process is similar to commercial canning and is used for a variety of ready-to-eat meals such as stews, pastas, and desserts. Thermostabilized foods can be stored at room temperature and do not require refrigeration. This technique ensures microbial safety and extends shelf life up to 24 months (Kloeris & Perchonok, 2023).

6.3. Irradiation: Food irradiation uses ionizing radiation to kill bacteria, viruses, and insects without significantly altering the food's texture or taste. It is particularly useful for sterilizing high-protein items such as meat and poultry. These foods are vacuum-packed in multilayered foil pouches and are ready-to-eat. Irradiated space food helps reduce the risk of foodborne illness and is especially beneficial for long-duration missions where microbial control is vital (FAO, 2021).

6.4. Dehydration: In addition to freeze-drying, conventional dehydration is also used for items like fruits, cereals, and snacks. The process removes moisture through heat and airflow, making the food lighter and more compact. While less effective than freeze-drying at preserving nutrients, dehydration is simpler and suitable for less moisture-sensitive items.

6.5. Vacuum Packaging and Modified Atmosphere Packaging (MAP): Vacuum sealing removes air from food packaging to reduce oxidation and microbial growth. Modified atmosphere packaging replaces oxygen with inert gases such as nitrogen or carbon dioxide to prolong shelf life and prevent spoilage. These packaging methods are combined with oxygen and moisture barrier materials to protect sensitive food components (NASA, 2022).

6.6. Cleanroom and Aseptic Processing: To meet the stringent sterility standards for space missions, space foods are often prepared in cleanroom environments with high levels of sanitation and quality control. Aseptic processing involves sterilizing food and packaging separately and then filling them under sterile conditions. This minimizes contamination and extends the shelf life of high-risk foods (Tang *et al.,* 2021).

6.7. Emerging Techniques

- Innovative technologies are being explored to improve the nutritional and sensory quality of space food. These include:

- Microwave-Assisted Thermal Sterilization (MATS): This method uses microwaves to rapidly heat food in sealed containers, reducing heat exposure and preserving more nutrients and flavor.
- High-Pressure Processing (HPP): Food is exposed to high hydrostatic pressure to inactivate microorganisms without high temperatures, maintaining fresh-like qualities.
- 3D Food Printing: NASA and research institutions are developing 3D printing systems to customize meals using edible pastes and powders. This could allow for flexible menu options and better use of stored ingredients.

7. Nutritional Stability of Space Food

Ensuring the nutritional stability of space food over extended periods is a crucial component of mission planning for long-duration spaceflights. As astronauts rely solely on pre-packaged and preserved foods for months or even years, any degradation in nutrient content can jeopardize their health, cognitive function, and overall mission success.

7.1. Nutrient Degradation Over Time: Several vitamins and sensitive nutrients degrade during prolonged storage, even when foods are properly processed and packaged. Research shows that vitamins C, B1 (thiamine), B6, and folate are particularly susceptible to degradation. For example, vitamin C can decline by over 50% within one year of ambient storage, especially in irradiated and thermostabilized foods (Zwart *et al.,* 2021). Similarly, thiamine degradation has been observed in both meat and grain-based items during long-duration storage.

7.2. Food Matrix and Packaging Influence: The nutrient retention of space food is significantly influenced by the food matrix and packaging type. Freeze-dried fruits and vegetables generally maintain higher levels of vitamins compared to retort-packaged or irradiated foods. Packaging that provides effective oxygen and light barriers helps preserve lipid-soluble vitamins like A, D, and E. Studies also suggest that bread products fortified with thiamine mononitrate retain more B1 compared to natural meats due to stability of the synthetic vitamin form (Smith *et al.,* 2020).

7.3. Micronutrient Loss and Health Implications: The potential for micronutrient deficiencies over time has led to increased focus on multiyear nutritional stability. Deficiencies in vitamin D, K, potassium, and calcium are of particular concern due to their roles in bone health, cardiovascular function, and immune response. This is especially critical in microgravity, where bone demineralization is accelerated. Food scientists are now assessing nutrient delivery models that combine stable food matrices, supplements, and post-processing fortification techniques (Cooper *et al.,* 2021).

7.4. Long-Term Storage Conditions: Ambient storage at 21°C is standard for space foods, but even at this controlled temperature, oxidative and enzymatic degradation occurs. NASA's food systems aim for a minimum shelf life of 18–24 months; however, planned Mars missions will require food with at least a 5-year stability. This has prompted the evaluation of alternative preservation techniques such as vacuum microwave drying and oxygen-absorbing technologies (Kloeris & Perchonok, 2023).

7.5. Monitoring Nutrient Stability: To ensure astronauts continue to receive adequate nutrition throughout a mission, extensive monitoring of food nutrient content is conducted preflight and postflight. This involves analytical testing for vitamin content, degradation product formation, and microbial activity. Emerging technologies such as biosensors and smart packaging may soon allow real-time monitoring of nutrient levels onboard spacecraft (NASA, 2022).

7.6. Current Strategies and Future Directions: NASA and other space agencies are now exploring strategies such as preflight nutrient overfortification, packaging innovations, and controlled environment agriculture. Growing fresh food onboard spacecraft, such as lettuce or microgreens, may help replenish labile nutrients and improve dietary variety and morale. Research into genetic modifications of crops to enhance shelf-stable nutrients is also under way (Tang *et al.,* 2021).

8. Future Technologies and Materials

As human space exploration advances toward longer missions to the Moon, Mars, and beyond, the need for sustainable, intelligent, and efficient food systems becomes increasingly vital. Future technologies and materials for space food systems are being developed to reduce waste, extend shelf life, support in-situ resource utilization, and improve astronaut health and morale.

8.1. Smart Packaging Systems: One of the major advancements in space food packaging is the development of smart or intelligent packaging. These systems incorporate sensors, indicators, or embedded technology to monitor temperature, humidity, microbial contamination, and even nutrient degradation in real-time. By providing dynamic feedback, smart packaging enhances food safety and allows astronauts to assess food quality before consumption (Kloeris & Perchonok, 2023).

8.2. Biodegradable and Edible Packaging: To address concerns about solid waste accumulation in long-duration missions, researchers are exploring biodegradable and even edible packaging materials. Polymers derived from starch, chitosan, and bacterial cellulose are being studied for their biodegradability and strength. These materials reduce the environmental burden of packaging waste and align with sustainability goals (Tang *et al.,* 2021).

8.3. Radiation-Resistant Coatings and Barriers: Space foods are exposed to cosmic radiation, which can accelerate nutrient degradation and affect food safety. Future packaging materials are being designed to incorporate radiation-resistant coatings, such as those made with polyethylene or melanin-rich fungi. These barriers not only protect the contents from radiation but also help preserve the structural integrity of the packaging during extended space travel (Douglas *et al.,* 2022).

8.4. 3D Food Printing Technology: 3D printing holds promise for creating customizable, on-demand meals using stored ingredients. NASA and private research institutions are developing food printers that use powdered or paste-like inputs to produce layered foods tailored to individual nutritional and psychological needs. This approach can reduce packaging, enhance variety, and optimize nutrient delivery (Zhang *et al.,* 2023).

8.5. Controlled Environment Agriculture (CEA): Future space missions may rely on onboard food production systems such as hydroponics, aeroponics, or bioreactors. These controlled systems enable astronauts to grow fresh produce and even cultivate protein-rich organisms like algae and fungi. CEA technologies help provide labile nutrients that degrade in stored foods and support dietary diversity, morale, and psychological well-being (Massa *et al.,* 2021).

8.6. Advanced Preservation Methods: Emerging preservation techniques like pulsed electric fields (PEF), microwave-assisted thermal sterilization (MATS), and high-pressure processing (HPP) are under evaluation for their ability to extend food shelf life without compromising nutritional and sensory quality. These technologies offer lower thermal loads, faster processing, and better retention of heat-sensitive nutrients (Cooper *et al.,* 2021).

8.7. Artificial Intelligence and Nutritional Personalization: AI-driven software is being investigated to analyze biometric data and recommend personalized diets for astronauts. Such systems could adapt meal composition in real time based on physical activity, stress levels, or medical conditions. Integration with 3D printing and smart packaging would enable responsive and adaptive food systems in future missions (Smith & Zwart, 2020).

Conclusion:

Space food technology has evolved significantly, transforming from basic survival rations to complex, nutritionally balanced systems. It now addresses not only the physical health of astronauts but also psychological well-being, efficiency in packaging, and long-term food stability. Current techniques like freeze-drying, irradiation, and thermostabilization help maintain safety and nutrition, while innovative packaging materials improve usability and reduce waste.

Nutrient degradation remains a challenge, particularly for long missions, leading to strategies such as nutrient fortification and potential in-space cultivation. Technologies like 3D food printing, smart packaging, and AI-driven personalization represent the future of space nutrition.

Beyond space, these innovations have impacted global food safety, with systems like HACCP now used worldwide. As space missions extend further, continued advancements in food systems will be essential to sustaining human health in extreme environments.

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Contemporary Developments in Science and Technology Volume I

ISBN: 978-93-48620-02-6

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ISBN 978-93-48620-02-6