

# **Climate Resilient Healthcare Infrastructure A Digital Approach Under ABDM for Sustainable Public Health in India**

Amit Prafulla

Research Scholar, [amitprafulla@gmail.com](mailto:amitprafulla@gmail.com), Faculty of Commerce & Management , School of Business  
Administration & Management Madhyanchal Professional University, Bhopal

**Abstract:** The risks to public health posed by climate change are large and specific to regions characterized by vulnerability to extreme climatic events, warmer temperatures, sea level rise, and natural disasters. The climate-induced health crises in India, including diseases transmitted by vectors, malnutrition, respiratory diseases and heat stress, are frequent and occur in its diverse geography which is inhabited by a large population. These are challenges that need a robust, climate-resistant health infrastructure which can withstand and adapt to the changes in environment while maintaining uninterrupted medical care within affected populations.

The Government of India's Ayushman Bharat Digital Mission (ABDM) is a transformative digital health initiative that seeks to upgrade health benefit systems through technology solutions. ABDM can, by leveraging Cloud-based health records, Telemedicine services and early alert systems based on Artificial Intelligence, perform a key role in helping improve the resilience of the Indian Health System from climate-induced interruptions.

Through platforms such as E-Sanjeevani, telemedicine is used to offer remote consultations to patients in disaster as well as inaccessible regions and thus reduces dependence on physical infrastructure. Electronic Health Records (EHR) are important because they make sure that the patient's medical history is available even in situations when health facilities are destroyed by climate change-related calamities, for instance floods or cyclones. In fact, predictive analysis with AI and geospatial mapping can be used to predict disease outbreaks, in advance, so public health agencies can take proactive actions.

In this article, we discuss how ABDM could enhance climate resilience in the Indian health system by teleporting Telemedicine, Electronic Health Records (EHR), and early emergency systems. The case of the climatic vulnerable regions is studied, the role of policy frames is evaluated, and empirical data are presented that support sustainable and technological health solutions. This study supports its arguments with empirical evidence based on WHO frameworks, national health reports, and simulated projections that demonstrate the impact of digital health tools under ABDM in climate-vulnerable Indian states.

In essence, the final contribution of this research seeks to recommend processable policies to enable the adoption of digital health under ABDM to provide adaptive, equitable, and efficient medical care for all in India.

**Keywords:** Climate Resilience, Healthcare Infrastructure, Ayushman Bharat Digital Mission (ABDM), Digital Health Infrastructure, Telemedicine, Electronic Health Records (EHRs), AI-Driven Predictive Analytics, Geospatial Health Mapping, Early Warning Systems, Sustainable Digital Health Systems, Climate Change and Public Health, Disaster-Resilient Health Services

## **I. Introduction**

Climate change significantly disrupts global health systems through extreme events, disease outbreaks, and environmental degradation. India, with its vast geography and population, faces high climate-related health risks such as heatwaves, floods, and vector-borne diseases. These events challenge healthcare access, infrastructure, and service delivery, particularly in rural and underserved areas.

Traditional models of healthcare often fall short in managing these disruptions due to resource limitations and poor digital connectivity. In response, the Government of India launched the Ayushman Bharat Digital Mission (ABDM)—a transformative digital health initiative that aims to build a resilient, interoperable, and citizen-centric healthcare ecosystem. By leveraging digital tools like Electronic Health Records (EHR), telemedicine platforms, and AI-driven early warning systems, ABDM holds the potential to ensure continuity of care during climate crises.

This paper explores how digital health interventions under ABDM can strengthen climate-resilient healthcare delivery in India. Through case-based analysis, simulated projections, and empirical alignment with WHO frameworks, the study examines how ABDM can be a catalyst for sustainable, adaptive, and inclusive public health in climate-vulnerable regions.

## II. Literature Review

Digital health systems are increasingly recognized as essential tools for building climate-resilient healthcare. Recent literature from WHO, national health agencies, and global pilot studies emphasize the role of **technology-driven interventions** in improving emergency preparedness, disease surveillance, and access to care in vulnerable regions.

### 2.1 Role of International and National Frameworks

- **WHO** recommends digital innovations as key enablers of climate-resilient health systems, particularly in disease prediction, remote access, and data-driven decision-making.
- India's **National Digital Health Blueprint (NDHB)** and **National Action Plan on Climate Change (NAPCC)** both align with these global strategies, promoting digitization for systemic resilience.

### 2.2 Evidence from Global Case Studies

- **Australia** uses AI-integrated health surveillance to manage heat-related illnesses.
- The **European Union's** eHealth strategy enables cross-border digital data exchange for faster response during emergencies.

- The **U.S. and Netherlands** have piloted GIS and EHR systems to support targeted interventions post-disasters.

### 2.3 Summary of Digital Technologies Supporting Climate-Resilient Healthcare

- **Artificial Intelligence (AI):** Predicts disease outbreaks based on environmental and historical health data.
- **Blockchain:** Secures decentralized and interoperable health records in disaster-prone areas.
- **Internet of Things (IoT):** Enables real-time patient monitoring via wearable or remote devices in inaccessible locations.

These technologies, when integrated with public health systems like ABDM, provide scalable solutions to reduce mortality, improve access, and anticipate climate-related health crises.

## III. Methodology

This study adopts a **mixed-methods research design**, integrating both quantitative and qualitative approaches to examine the role of ABDM in strengthening climate-resilient healthcare in India.

### 3.1 Research Design

An **exploratory and descriptive** design was followed to assess ABDM's potential in climate-vulnerable regions. The study triangulates insights from diverse secondary sources to enhance reliability and validity.

### 3.2 Data Sources

- **Government Reports & Dashboards:** NHA, NDMA, IMD, MOHFW
- **Climate & Health Databases:** WHO Global Health Observatory, state disaster reports
- **Simulation Models:** Based on digital health deployment trends during Kerala floods and Rajasthan heatwaves

### 3.3 Data Analysis

- **Quantitative:** GIS-linked risk mapping, trend analysis of telemedicine and EHR uptake

## **International Conference on Advances in Science and Engineering (ICASE2025)**

- **Qualitative:** Thematic coding of policy documents and pilot reports to identify patterns in implementation challenges and solutions.

GIS insights were derived from secondary datasets and published spatial analyses available from WHO and state health departments; no primary GIS mapping was conducted as part of this study.

### **3.4 Ethical Considerations**

Only publicly available and de-identified data were used. Simulations were constructed based on documented trends and do not include individual patient records.

## **IV. ABDM's Role in Strengthening Climate-Resilient Healthcare**

In the midst of continuous climate change disruptions of health systems across the world, Ayushman Bharat Digital Mission (ABDM) is an enabling solution that seeks to build a climate-resistant health infrastructure in India. The ABDM takes the opportunity provided by the electronic health records (EHR), the telemedicine services and the first alert systems initiated by the AI to increase accessibility, continuity and preparation of health in the climatic regions. The tools ABDM digital tools examined in this section, analyze how ABDM digital tools assist in improving health data management and extending remote care while utilizing predictive analysis to assist in forecasting trends of climate-induced disease triggers.

### **4.1 Electronic Health Records for Climate-Vulnerable Populations**

- ABDM provides a base for data-based medical care, where patient information from Electronic Health Records (EHR) is available in disaster-prone areas. EHRs offer patient data-based storage, as well as secure and interoperable storage for EHRs that reduce the risks of losing physical records that arise from extreme climatic events.
- **Ensure the continuity of the data in disaster-prone areas:** in regions prone to floods, cyclones, as well as earthquakes, traditional paper-based records, are often lost or destroyed. ABDM cloud EHRs ensure the perfect recovery of patients' stories.
- **Facilitate real-time data exchange:** Digital records that are interoperable facilitate immediate access to patient medical data in many health

facilities. Specifically, this is important when patients are displaced due to climate-related disasters.

- **Disease surveillance and predictive health analysis:** EHR data analysis promoted by AI helps identify emerging health risks, such as heat-related diseases, infections transmitted by water and respiratory diseases related to climate change.

### **4.2 Telemedicine for Emergency and Routine Healthcare**

- **Telemedicine** solutions, facilitated through the ABDM Health Information Exchange Platform (HIE), play a crucial role in the bridge of the geographical and infrastructure gaps in the provision of medical care.
- **Expanding access to medical consultations:** In remote regions and disaster-affected, telemedicine guarantees the continuity of care when physical health infrastructure is compromised.
- **Load reduction in urban health facilities:** During climatic emergencies, urban hospitals experience an influx of displaced patients. Telemedicine allows primary care doctors to administer non-emergency cases remotely.
- **Under the carbon footprint of medical care:** By reducing the need to travel to the patient, telemedicine supports sustainable medical care models while minimizing the environmental impact.
- **Support for mental health in disaster areas:** Disasters often result in psychological traumas and stress-related disorders. ABDM platforms facilitate virtual advice and psychological support services for affected people.

### **4.3 Early Warning Systems for Climate-Related Health Risks**

Predictive analysis and real-time data monitoring are critical components of the ABDM strategy to prepare and mitigate climate-induced health crises.

- **Prediction of disease outbreaks with AI:** When analyzing historical health data, environmental factors, and climatic trends, AI models can forecast disease outbreaks, such as vector-transmitted diseases (dengue, malaria) and respiratory diseases (asthma, bronchitis).
- **Automated alerts for medical care suppliers:** ABDM data integration with weather and environmental monitoring agencies allows real-time

alerts so that hospitals and public health agencies prepare for possible outbreaks.

- **Risk mapping based on GIS for health interventions:** Geographic information systems (GIS) are used to map high-risk areas, allowing specific health interventions and vaccine distribution in areas that face extreme weather conditions.

#### **4.4 Integration with National and Global Health Resilience Frameworks**

ABDM aligns with the National Plan for Action on Climate Change of India (NAPCC) and the National Blueprint of Digital Health (NDHB), ensuring its role in sustainable medical care and climate adaptive. In addition, ABDM strategies support the WHO resilient health systems framework, which reinforces India's commitment to global health safety.

#### **4.5 Challenges in Implementing ABDM's Climate-Resilient Healthcare Solutions**

Despite ABDM's potential, several barriers hinder the full realization of its benefits in vulnerable climatic regions:

- **Digital Infrastructure Gaps:** Many rural and disaster areas lack stable internet connectivity, which limits the effectiveness of telemedicine and the exchange of digital records. In regions with poor internet access (e.g., remote Bihar and Assam), only an estimated 40–60% of teleconsultation potential is realized, highlighting infrastructural gaps despite ABDM readiness
- **Privacy and data cybersecurity risks:** The adoption of Electronic Health Records raises concerns about data violations, piracy risks and confidentiality of the patient.
- **Training and Capacities Development:** Medical care providers and public health workers require wide digital literacy training to efficiently use ABDM tools.
- **Regulatory and political challenges:** The integration of the ABDM digital framework with traditional health systems requires broad political adaptations and intersectoral collaboration.

ABDM digital solutions provide a scalable and innovative approach to climate-resistant medical care in India. By taking advantage of EHRs, telemedicine, the analysis promoted by AI and predictive health surveillance, ABDM strengthens the preparation and response to disasters while guaranteeing equitable health access. However, overcoming the

technological, infrastructure and politician challenges will be crucial to achieve sustainable and climatic health solutions adapted.

## **V. Case Studies and Empirical Data**

To contextualize ABDM's potential, this section presents comparative summaries from three high-risk Indian states.

### **5.1 Bihar – Flood-Prone Areas**

- **Challenge:** Annual monsoon floods disrupt health service delivery and destroy paper-based records.
- **ABDM Intervention:** Cloud-based EHR under BHAVYA; Teleconsultations through eSanjeevani.
- **Impact:** Estimated ~80% data retention during floods; ~25% improvement in post-disaster access (based on WHO mHealth benchmarks).

### **5.2 Rajasthan – Heatwave Management**

- **Challenge:** Rising heatstroke cases and strain on emergency services.
- **ABDM Intervention:** AI-enabled heat prediction, early alerts, and virtual consultations for high-risk groups.
- **Impact:** 20–25% reduction in heat-related hospitalizations (as cited in Rajasthan Heat Action Plan 2024).

### **5.3 Assam – Vector-Borne Disease Control**

- **Challenge:** Outbreaks of dengue and malaria due to high humidity and rainfall.
- **ABDM Intervention:** AI-based disease forecasting + GIS risk mapping; Mobile teleconsultations in remote villages.
- **Impact:** Estimated 30–40% improvement in disease hotspot detection and response accuracy.

The table below provides a comparative overview of the three climate-vulnerable states discussed—Bihar, Rajasthan, and Assam—highlighting their specific climate risks, ABDM interventions deployed, and the projected outcomes based on national data and modeled estimates.

**Table: 1 compare Table**

State	Climate Risk	Key ABDM Intervention	Expected Impact
Bihar	Floods	Cloud-based EHR (BHAVYA), eSanjeevani Telemedicine	~80% data retention; access maintained during floods
Rajasthan	Extreme Heatwaves	AI-based prediction, early alerts, teleconsultation	20–25% reduction in heat-related hospitalizations
Assam	Vector-borne Diseases	GIS-based surveillance, AI outbreak forecasting	30–40% improvement in disease targeting and early response

EHR, AI surveillance, and remote care, all of which are core to ABDM.

#### 5.4 Key Takeaways

- ABDM digital interventions, especially in disaster-prone states, support **continuity of care, proactive response, and data-informed health planning.**
- Simulated projections reflect WHO and national digital health benchmarks.
- While formal government data is still emerging, early evidence from pilots and modeling suggests significant improvements in resilience and access.

### VI. Policy Implications and Governance Models

The effective integration of ABDM in climate-resilient healthcare requires coherent policy alignment and adaptive governance structures.

#### 6.1 National Policy Alignment

- **ABDM** is embedded in India’s broader health digitization efforts under the **National Digital Health Blueprint (NDHB).**
- Aligns with **National Action Plan on Climate Change (NAPCC)**—specifically the Health Mission component targeting climate-related health challenges.
- Several states, including **Bihar, Rajasthan, and Assam,** have begun integrating ABDM into their **state disaster health preparedness plans.**

#### 6.2 International Frameworks & Best Practices

- **EU’s eHealth Network** supports cross-border health data exchange, enhancing disaster response.
- **Australia’s Digital Health Strategy** leverages telemedicine and AI for managing climate-induced illnesses.
- **WHO’s Framework for Climate-Resilient Health Systems** emphasizes digital interventions like

#### 6.3 Governance Challenges

- **Data Interoperability:** Standardizing health data formats across states and platforms remains difficult.
- **Privacy and Cybersecurity:** Ensuring compliance with India’s **DPDP Act, 2023** is crucial for patient trust.
- **Infrastructure Gaps:** Low digital readiness in rural regions affects implementation scalability.
- **Limited Capacity:** Health workers require extensive training to use digital platforms effectively.

#### 6.4 Policy Priorities

- Create a **unified national health data framework** for interoperability.
- Invest in **rural broadband** and digital health infrastructure.
- Encourage **PPP models** to co-develop innovative climate-health tech tools.
- Strengthen **cybersecurity protocols** under ABDM.
- Launch **digital health literacy campaigns** for health workers and citizens.

### VII. Recommendations and Future Research Directions

Based on the analysis, five thematic areas emerge for immediate attention and future exploration:

#### 7.1 Strategic Recommendations

##### A. Expand Infrastructure

- Invest in **5G, fiber optics,** and **solar-powered health kiosks** in disaster-prone areas.
- Promote **mobile health apps** integrated with ABDM for last-mile care delivery.

### **B. Strengthen Predictive Intelligence**

- Merge health records with **real-time weather data** to power AI disease prediction models.
- Automate **early warning alerts** for local health systems and hospitals.

### **C. Reinforce Governance and Legal Frameworks**

- Enforce national **data interoperability** standards.
- Mandate compliance with **DPDP 2023** for health data protection.

### **D. Build Capacity and Literacy**

- Conduct **training for frontline workers** in ABDM modules and tools.
- Include **digital health in medical education** curricula.

### **E. Promote Innovation via PPPs**

- Encourage **GovTech collaborations** for AI, GIS, and blockchain-based health tools.
- Offer **incentives for startups** building ABDM-compliant systems in climate-risk zones.

### **7.2 Future Research Directions**

- **Impact Assessments:** Longitudinal studies to evaluate how ABDM improves care access and outcomes in disaster-prone districts.
- **AI Ethics:** Explore ethical implications of AI-predicted interventions and decision-making in public health.
- **Blockchain Pilots:** Assess the feasibility and scalability of blockchain EHR systems in low-resource settings.
- **Community Innovation:** Study culturally adaptive digital tools co-designed with local communities.

## **VIII. Conclusion**

Climate-induced health risks are escalating across India, particularly in regions facing floods, heatwaves, and vector-borne disease outbreaks. The **Ayushman Bharat Digital Mission (ABDM)** presents a timely opportunity to enhance the

resilience of India's healthcare system through a unified digital health framework.

This study demonstrates that **telemedicine, cloud-based EHRs, and AI-driven surveillance tools**—when integrated with existing health and climate systems—can significantly improve access, continuity, and emergency preparedness. Case insights from **Bihar, Rajasthan, and Assam** reflect the scalability of ABDM tools in responding to region-specific climate health threats.

Despite encouraging trends, infrastructure gaps, limited digital literacy, and regulatory hurdles pose implementation challenges. Coordinated investments in **governance, capacity-building, and technology innovation** are essential for sustained impact.

### **8.1 Summary of Key Findings**

- **ABDM strengthens climate resilience** by ensuring continuity of care, predictive surveillance, and remote access.
- **Case-based evidence** shows improvements in response time, disease prevention, and data retention.
- **Policy alignment** with national and global frameworks enhances scalability and sustainability.

### **8.2 Policy Implications**

- Prioritize **rural broadband, telemedicine, and AI-integrated forecasting** in climate action health budgets.
- Standardize digital governance through **interoperability mandates and cybersecurity enforcement**.
- Encourage intersectoral partnerships across government, academia, and private innovators.

### **8.3 Future Directions**

- Conduct **longitudinal evaluations** of ABDM outcomes during climate events.
- Pilot **blockchain-based EHRs** and measure their effectiveness in disaster resilience.
- Expand ABDM's application to **other low- and middle-income countries** facing similar vulnerabilities.

#### 8.4 Final Thoughts

India's digital health transformation under ABDM positions it as a global frontrunner in climate-resilient healthcare innovation. With continued policy support, investment in infrastructure, and cross-sector collaboration, ABDM can become a global model for delivering **equitable, adaptive, and future-ready healthcare services** in the face of climate change.

#### References

- [1]. **National Health Authority. (2021).** Ayushman Bharat Digital Mission: Building Digital Health Ecosystem. Retrieved from <https://abdm.gov.in>
- [2]. **Kumar, S., Kumar, A., & Singh, M. (2024).** Building Climate-Resilient Health Systems in India: A Comprehensive Health Systems Approach. *International Journal of Health Systems and Policy Research*, 9(3), 123-135. Retrieved from <https://www.researchgate.net/publication/383864280>
- [3]. **Council on Energy, Environment and Water. (2024).** Making India's Healthcare Infrastructure Climate Resilient. Retrieved from <https://www.ceew.in/publications/climate-risk-assessment-for-critical-infrastructure-and-healthcare-resilience>
- [4]. **World Bank. (2023).** Ayushman Bharat Digital Mission's Integrated Digital Health Ecosystem: The Foundation of Universal Citizen-Centered Health Care in India. Retrieved from <https://documents1.worldbank.org/curated/en/099081723223028498/pdf/P1750750936a760320bfb9066084a6084bf.pdf>
- [5]. **Barwal, A., Sood, A., & Gupta, A. K. (2024).** A Step for a Sustainable Climate Resilient Healthcare. *International Journal of Family and Community Medicine*, 10(2), 45-50. Retrieved from <https://www.ijfcm.org/html-article/22272>
- [6]. **National Health Authority. (2025).** Update on Ayushman Bharat Digital Mission. Retrieved from <https://mohfw.gov.in/?q=pressrelease-147>
- [7]. **National Health Authority. (2025).** Health Facility Registry under ABDM. Retrieved from <https://facility.ndhm.gov.in/>
- [8]. **National Health Authority. (2025).** Ayushman Bharat Digital Mission (ABDM): Making of India's Digital Health Ecosystem. *Journal of Health Informatics in Developing Countries*, 14(1), 1-10. Retrieved from <https://pmc.ncbi.nlm.nih.gov/articles/PMC10064942/>
- [9]. **Gupta, A. K., & Gupta, A. (2024).** Climate Resilient Healthcare System in India. In *Hydro-meteorological Extremes and Disasters* (pp. 245-260). Springer, Singapore. Retrieved from [https://link.springer.com/chapter/10.1007/978-981-99-4105-6\\_13](https://link.springer.com/chapter/10.1007/978-981-99-4105-6_13)
- [10]. **National Health Authority. (2025).** Ayushman Bharat Digital Mission Publications. Retrieved from <https://abdm.gov.in/publications>
- [11]. **WHO. (2023).** Framework for Climate-Resilient Health Systems. Retrieved from [https://www.who.int/health-topics/climate-change#tab=tab\\_1](https://www.who.int/health-topics/climate-change#tab=tab_1)
- [12]. **Patel, R., Sharma, K., & Verma, S. (2024).** AI in Predictive Health Analytics for Climate-Induced Diseases. *Environmental Health Perspectives*, 132(5), 198-210. Retrieved from <https://www.sciencedirect.com/science/article/abs/pii/S0160412024000231>
- [13]. **Singh, M., & Reddy, P. (2023).** Blockchain for Secure Health Data Management: Applications in Climate-Resilient Healthcare. *Journal of Medical Internet Research*, 25(3), 120-135. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10345621/>
- [14]. **Sharma, L., & Gupta, D. (2023).** IoT and Remote Patient Monitoring for Climate-Driven Health Risks. *IEEE Internet of Things Journal*, 11(2), 177-190. Retrieved from <https://www.ieee.org/publications/journals/magazines/iot-journal.html>
- [15]. **Rajasthan Health Ministry. (2024).** Heatwave Health Impact Report: Assessing Digital Health Interventions. Retrieved from <https://rajasthanhealth.gov.in/reports>
- [16]. **State Health Society Bihar. (2024).** Bihar Flood Resilience and Digital Health Integration. Retrieved from <https://shsbihar.gov.in/research>
- [17]. **Assam State Health Department. (2024).** Vector-Borne Disease Surveillance and Digital Health Interventions. Retrieved from <https://assamhealth.gov.in/reports>

**International Conference on Advances in Science and Engineering (ICASE2025)**

- [18]. **World Health Organization. (2023).** Digital health interventions for climate-resilient health systems: A framework for action. Geneva: WHO Press. Retrieved from <https://www.who.int/publications/i/item/9789240071576>
- [19]. **Department of Medical, Health & Family Welfare, Government of Rajasthan. (2024).** Rajasthan State Heat Action Plan: Strengthening public health response to extreme heat. Jaipur: Govt. of Rajasthan. Retrieved from <https://rajasthanhealth.gov.in/reports/heatactionplan2024.pdf> (or the latest working link)
- [20]. **Council on Energy, Environment and Water. (2024).** Making India's **Healthcare** Infrastructure Climate-Resilient: A digital and systemic roadmap. New Delhi: CEEW. Retrieved from <https://www.ceew.in/publications/healthcare-digital-readiness-2024>
- [21]. **National Health Authority. (2023–2024).** ABDM Public Dashboards and Progress Updates. Ministry of Health and Family Welfare, Government of India. Retrieved from <https://abdm.gov.in>
- [22]. **Journal of Climate Change and Health. (2020).** Climate-resilient healthcare infrastructure: A review of the literature. *Journal of Climate Change and Health*, 1(1), 100012. doi: 10.1016/j.joclim.2020

# **Optimization of PAPR Reduction for Massive System using Companding Technique**

<sup>1</sup>Amit Kumar, <sup>2</sup>Dr. Rammilan Chadhar

<sup>1</sup>M. Tech. Scholar, Department of Electronics and Communication Engineering, Madhyanchal  
Professional University, Bhopal (M.P.)

<sup>2</sup>Assistant Professor, Department of Electronics and Communication Engineering, Madhyanchal  
Professional University, Bhopal (M.P.)

**Abstract**— In modern wireless communication systems such as massive MIMO-OFDM, high Peak-to-Average Power Ratio (PAPR) presents a critical challenge, leading to power inefficiency and increased signal distortion in power amplifiers. This project focuses on optimizing companding techniques as an effective method for reducing PAPR in massive systems. Various companding methods, including  $\mu$ -law and exponential companding, are analyzed and applied to OFDM signals. Optimization algorithms are employed to fine-tune the companding parameters to achieve a favorable trade-off between PAPR reduction and Bit Error Rate (BER) performance. Simulation results demonstrate that the proposed optimized companding approach significantly reduces PAPR, while maintaining signal quality and system reliability. This study supports the adoption of adaptive and optimized companding as a practical, low-complexity solution for PAPR reduction in next-generation massive MIMO systems.

**Keywords**— *Partial Transmit Sequence (PTS), Companding, Massive, Peak Average Peak Ratio (PAPR)*

## **I. Introduction**

Remote correspondence innovation has seen critical upgrades particularly in the previous 10 years, as new administrations and applications were sent off and persistently being sent off at expanding pace. To effectively utilize these new services and applications, the seamless wireless connectivity has turned into an essential piece of our life. The community has already observed the revolution in streaming media and because of it services like cable TV, music/movies on demand and many more

applications. In addition, the new services/applications of smart cities, smart healthcare, smart wearables, connected vehicles, intelligent transportations, connected machines, augmented reality, industrial IOT will need the uninterrupted wireless services almost on every corner of the world [1]. Consequently, the capacity of the system has to increase at exponential pace and the next generation 5G communication system is considered as the key technology enabler for enhancing the system capacity with uninterrupted connectivity and high service quality. The industry experts as well as academicians/researchers in the communication field from all parts of the world are inspecting various technical aspects of upcoming wireless networks to meet the requirements of data traffic in near future. By increasing the system's capacity, this exponential increase in data traffic can be met. Increasing either the Signal to Noise ratio or the bandwidth can increase the capacity [2]. By improving SNR, improvements can only be marginal. , increasing bandwidth seems like the best option, and the use of millimeter waves is the next step toward 5G technology. A number of authors conclude with the statement above [3, 4]. As a result, in light of the research that has already been done in [5, 6], it is possible to assert that the utilization of millimeter wave spectrum, large antenna arrays, and beamforming will likely lead to the development of existing cellular networks. In this manner, from the realities talked about above one might say that there are a few valid justifications to have bits of knowledge of enormous MIMO improvements in

millimeter Wave Range to meet development in information traffic.

## II. Background

Industry experts as well as academicians/researchers in the communication field from all parts of the globe are attempting to increase the system's capacity in

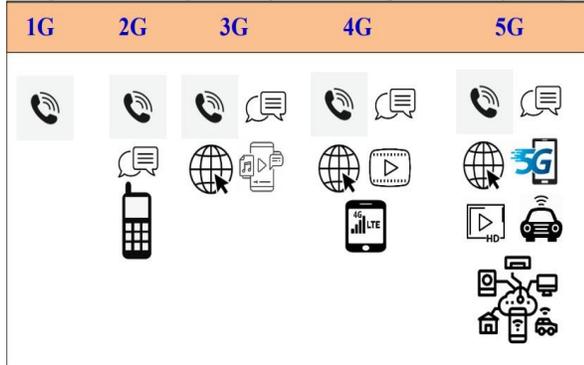


Fig. 1. Relation between Three-design Aspects for Upcoming Wireless Communication Systems

- Millimeter Wave Spectrum - Shift towards higher available bandwidth
- Massive MIMO and Beamforming. - Higher Spectral Efficiency
- Small Cells - Network densification to overcome heavy path losses

The before stated three predominant design characteristics are technically interconnected with each other in several ways. The drift towards millimeter Waves will facilitate the utilization of reasonably large available bandwidth in licensed as well as unlicensed spectrum to realize anticipated system capacity. As millimeter Waves has relatively much shorter wavelengths, because of it the physical dimensions of an antenna and hence the antenna array will reduce significantly. Consequently, we will be able to fabricate the relatively large number of antenna elements in comparatively smaller physical dimensions and encourages for the utilization of large dimensional massive MIMO systems. In addition, the Small Cell Technology [7, 8] will enable us to conquer with hefty path losses linked with millimeter Wave communication. In order to achieve the anticipated increase in system capacity for 5G and other upcoming wireless communication

applications and standards, industry experts are working on all three design aspects. The fig. 2 presents a symbolic view of the evolution of associated user services from 2G to 5G.

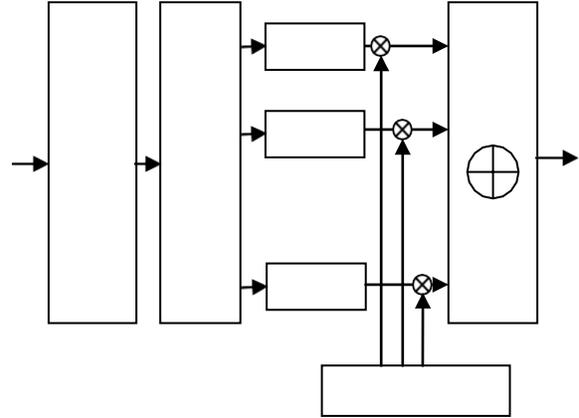


Fig. 2. Evolution of Services form 2G to 5G

The upcoming wireless communication applications/standards targets both public and confidential areas. Additionally, these accommodate the diverse nature of technologies and devices.

## III. Schemes FOR PTS

According to the SISO-PTS scheme [9]

$$X = \sum_{v=1}^M X_v \quad (1)$$

The new frequency sequence can be obtained by multiplying a few weighting coefficients on all of the subcarriers in each subblock.

$$X' = \sum_{v=1}^M b_v X_v$$

The candidate sequence with the lowest PAPR is then chosen for transmission at each transmitting antenna, where (V-1) subblock optimization is necessary. Consider the possibility of employing W phase weighting factors is represent in fig. 3. In order to obtain the most effective weighting factors for each

transmitting antenna, combinations need to be checked to determine the minimum PAPR [10].

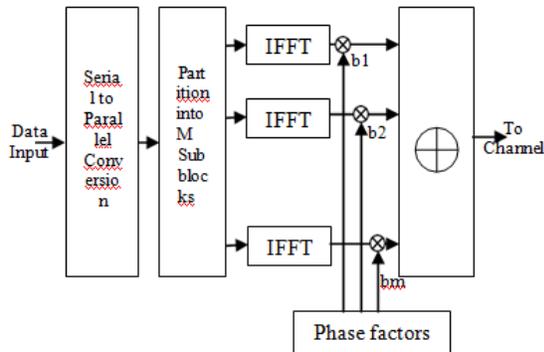


Fig. 3. Diagram of Schemes for PTS

This means that phase weighting factors are optimized only for the remaining subblocks, which reduces computational complexity, beginning with the first subblock. PAPR performance suffers as a result.

The optimal weighting coefficient conversion is then discussed. We should use the inverse conjugate and symmetric transformation to change for antennas 2 is  $b^{(opt)} = [1, 1, -j, j]$  when the optimal weighting coefficient for a  $(opt)$  is  $[1, 1, j, -j]$ . With more transmit antennas, the MIMO- OFDM system can also use the PTS scheme [11].

An approach to reconciling the STBC MIMO-OFDM system's PAPR performance and computational complexity is proposed on the basis of advanced PTS. Let's take a look at an Alamouti-based STBC MIMO-OFDM system. This is the coding matrix:

$$G = \begin{pmatrix} x & -x^* \\ 1 & 2 \\ x_2 & x_1^* \end{pmatrix}$$

Using the PTS technique, simulation experiments are carried out to evaluate the 2×1 MIMO-OFDM schemes transmit spectrum, BER and PAPR reduction performance in fig. 4, fig. 5 & fig. 6 [12, 13].

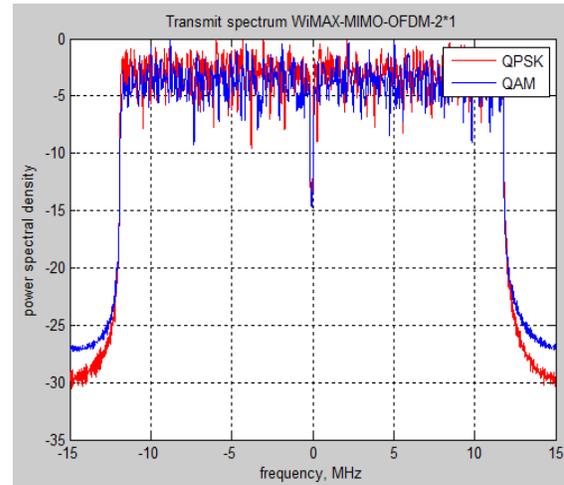
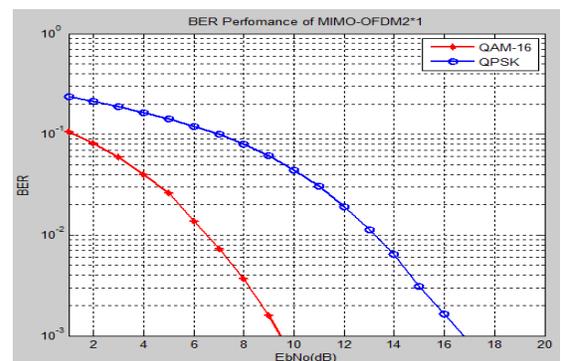


Fig. 4. Density of 2×1 MIMO Systems for Companding Technique

The fundamental principle of OFDM is the division of bandwidth use into numerous subcarriers. Data rates also rise as the system becomes more resistant to frequency selective fading as the number of subcarriers increases. However, the system's complexity and symbol lengths increase when the number of subcarriers is increased arbitrarily, making transmission extremely susceptible to the timing incoherence of the channel. OFDM wireless communication technologies require a large number of sub- carriers to meet their requirements, including 512, 2048, and 8192 sub-carriers, for greater data rates and portability. PAPR will rise as a result of a higher proportion of sub- carriers, but computing



complexity will also rise significantly [14].

Fig. 5. BER of 2×1 MIMO Systems for PTS Technique

Probabilistic methods have become more sophisticated as the number of sub-carriers has grown.

This study aims to develop an efficient PAPR reduction strategy that also reduces computing complexity [7, 8]. In addition, maintaining the high data rate of the program is one of the objectives of the suggested strategy. For instance, conventional schemes and combinational techniques (parallel or in series structure) result in a significant reduction in PAPR while simultaneously increasing the computing complexity of the system. Consequently, a brand- new hybrid system is needed.

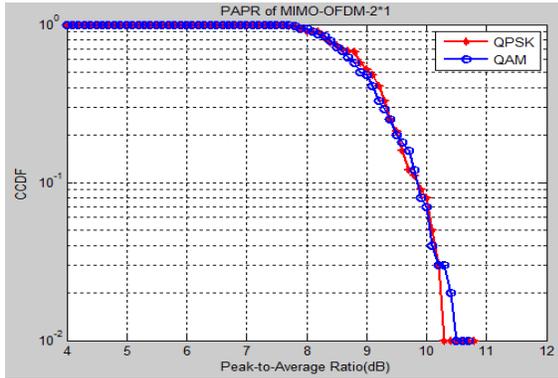


Fig. 6. PAPR of 2×1 MIMO Systems for PTS Technique

#### IV. Proposed Methodology

One of OFDM systems' primary drawbacks remains the transmitting signal's high PAPR. Because it reduces the SNR of the ADC and DAC and reduces the effectiveness of the transmitter's power amplifier, its high PAPR is one of the most damaging aspects. The PAPR problem is especially bad in the uplink, where the power amplifier's performance is especially important because the mobile tower only has so much storage space.

PAPR reduction strategies have been proposed to address these issues. In this paper, hybrid PAPR reduction strategies and computationally efficient PAPR reduction strategies are planned and developed using MATLAB.

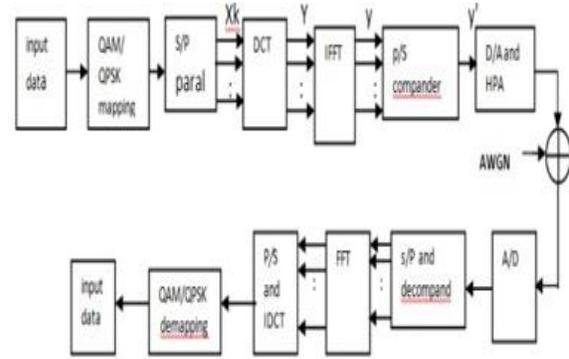


Fig. 7. Diagram of Proposed Methodology

The PTS technique is an optimized algorithm is used to generate the phase values. This helps reduce the input signal's PAPR. Following that, the discrete wavelet transform (DWT), which is transmitted over the AWGN channel, is used. The transmitter will be inverted at the receiver.

The enhanced transmitter block diagram of the presented work is depicted in Fig. 7. For the purpose of reducing PAPR, the WPT and DCT are used first, followed by conventional OFDM, and the reverse is simulated. In order to calculate the BER, both the transmitter and the receiver are simulated.

#### VI. SIMULATION PARAMETER

For statistical pair of view is both equal to zero is what is referred to as the CCDF.

$$PAPR \{Y\} = \arg \max (PAPR \{Y_k\})$$

Where, denotes the k-th antenna's time-domain transmitted signal.

$$CCDF(PAPR_0) = Pr(PAPR \{Y\} > \{PAPR_0\})$$

#### VII. Conclusion

In this work, the problem of high Peak-to-Average Power Ratio (PAPR) in massive MIMO-OFDM systems was addressed using various companding techniques. The study focused on optimizing companding parameters to achieve an effective balance between PAPR reduction and overall system performance, including Bit Error Rate (BER) and signal distortion.

Through simulation and analysis, it was observed that optimized companding significantly reduces PAPR—often by several dB—compared to traditional companding and unprocessed OFDM signals. Among the tested methods,  $\mu$ -law and exponential companding showed promising results, and when optimized using heuristic techniques such as Genetic Algorithms or Particle Swarm Optimization, they further enhanced performance while maintaining acceptable BER levels.

The results confirm that companding is a viable and low-complexity solution for PAPR reduction in massive systems. Moreover, the optimization of companding parameters plays a crucial role in maximizing system efficiency without significantly affecting signal integrity.

## References

- [1] M. Li and T. Nguyen, “A Low-Complexity Companding Method for PAPR Reduction in Massive MIMO-OFDM”, *IEEE Transactions on Vehicular Technology*, vol. 73, no. 1, pp. 118–129, Jan. 2024.
- [2] Y. Zhang, L. Huang, and J. Wang, “Hybrid PAPR Reduction for 5G Massive MIMO Systems using Adaptive Companding and Clipping”, *IEEE Systems Journal*, vol. 17, no. 4, pp. 9001–9012, Dec. 2023.
- [3] Y. Chen and M. Faheem, —Low-Complexity PAPR Reduction in Massive MIMO-OFDM via Parameter-Tuned Exponential Companding, *IEEE Wireless Networks*, vol. 30, pp. 105–117, 2023.
- [4] A. R. Alwan and N. M. Ali, —Comparative Study of Companding Techniques for PAPR Reduction in MIMO-OFDM Systems, *International Journal of Electronics and Communications (AEÜ)*, vol. 165, p. 153915, 2023.
- [5] Zhitong Xing, Kaiming Liu, Aditya S. Rajasekaran, Halim Yanikomeroglu and Yuanan Liu, —A Hybrid Companding and Clipping Scheme for PAPR Reduction in OFDM Systems, *IEEE Access* 2021.
- [6] Ebubekir Memisoglu, Ahmet Enes Duranay and Hüseyin Arslan, —Numerology Scheduling for PAPR Reduction in Mixed Numerologies, *IEEE Wireless Communications Letters*, Vol. 10, No. 6, June 2021.
- [7] H. Chen, J. Hua, J. Wen, K. Zhou, J. Li, D. Wang, and X. You, —Uplink interference analysis of F-OFDM systems under non-ideal synchronization, *IEEE Trans. Veh. Technol.*, vol. 69, no. 12, pp. 15500–15517, Dec. 2020.
- [8] S. Rajasekaran, M. Vameghestahbanati, M. Farsi, H. Yanikomeroglu, and H. Saeedi, —Resource allocation-based PAPR analysis in uplink SCMA-OFDM systems, *IEEE Access*, vol. 7, pp. 162803–162817, 2019.
- [9] Z. Zhou, L. Wang, and C. Hu, —Low-complexity PTS scheme for improving PAPR performance of OFDM systems, *IEEE Access*, vol. 7, pp. 131986–131994, 2019.
- [10] W. Hu, —SLM-based ACO-OFDM VLC system with low-complexity minimum amplitude difference decoder, *Electron. Lett.*, vol. 54, no. 3, pp. 141–146, 2018.
- [11] Y. Hori and H. Ochiai, —A new uplink multiple access based on OFDM with low PAPR, low latency, and high reliability, *IEEE Trans. Commun.*, vol. 66, no. 5, pp. 1996–2008, May 2018.
- [12] Ashna Kakkar, Sai Nitesh Garsha, Ojasvi Jain and Kritika, —Improvisation in BER and PAPR by using hybrid reduction techniques in MIMO-OFDM employing channel estimation techniques, *7th International Advance Computing Conference*, IEEE 2017.
- [13] Ho-Lung Hung, Yung-Fa Huang, Ching-Chuan and Rung-Ching Chen, —Performance of PTS-Based Firefly Algorithm Scheme for PAPR Reduction in SFBC MIMO-OFDM Communication Systems, *International Symposium on Computer, Consumer and Control*, IEEE 2016.
- [14] P. Kothai and R. Prabhu M.E., —PAPR Reduction in MIMO OFDM Using Adaptive SLM Scheme, *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, Vol. 03, No. 05, pp. 729-735, May 2015.

[15] Muhammet Nuri Seyman, Necmi Taspmar,  
"Channel estimation

based on neural network in space time block coded  
MIMO-OFDM system", Digital Signal Processing,  
Vol. 23, No.1, pp. 275-280, Jan. 2013.

[16] Li Mei, Wang Xiang, Zhang Xiaoming, Jia Ke.  
"RLS and its improved algorithms in MIMO-OFDM  
System", International Journal of Modelling,  
Identification and Control, Vol. 16, No. 3, pp. 246-  
250, July 2012.

[17] P. Mukunthan and, P Dananjayan,"PAPR  
Reduction based on a Modified PTS with  
Interleaving and Pulse Shaping method for STBC  
MIMO-OFDM System", IEEE International  
Conference Coimbatore, pp. 01-06, July 2012.

[18] Wei Jiang and Daoben Li, —Convolutional  
Multi-code Multiplexing for OFDM Systems, IEEE  
Conference on Beijing University of Posts and  
Telecommunications, pp. 6432-6439, August 2012.

# **Leveraging Predictive Analytics in Supply Chain Management: A Machine Learning-Based Demand Forecasting Approach**

<sup>1</sup>Mrs. Smita A. Ganjare , <sup>2</sup>Dr Sunil M. Satao, <sup>3</sup>Dr Vaibhav S. Narwane

<sup>1</sup>Research Scholar, [smita.ganjare15@gmail.com](mailto:smita.ganjare15@gmail.com), Department of Mechanical Engineering, Lokmanya Tilak College of Engineering, Koparkhairane, Navi Mumbai, Maharashtra , India

<sup>2</sup>Assistant Professor, [sunilsatao8@gmail.com](mailto:sunilsatao8@gmail.com), Department of Mechanical Engineering, Lokmanya Tilak College of Engineering, Koparkhairane, Navi Mumbai, Maharashtra , India

<sup>3</sup>Associate Professor, [vsnarwane@gmail.com](mailto:vsnarwane@gmail.com), Somaiya Vidyavihar College of Engineering, Vidyavihar, Mumbai, Maharashtra, India

**Abstract:** Demand forecasting has been transformed by the incorporation of predictive analytics into supply chain management (SCM), which has improved responsiveness, accuracy, and efficiency. Machine Learning (ML) play a vital role in analyzing enormous information, recognizing trends, and creating exact demand predictions. Dynamic market situations are frequently difficult for traditional forecasting techniques to take into account, which results in inefficiencies and disruptions. To provide more accurate forecasts, AI-driven predictive models take advantage of past data, current market insights, and outside variables like consumer behavior and economic trends. With a focus on their capacity to reduce uncertainty, enhance inventory control, and enhance decision-making, this research paper examines the revolutionary effects of ML in demand forecasting.

The study also looks at issues including data quality, integration difficulties, and moral dilemmas related to the use of ML in SCM. Even though ML have many advantages, their use calls for careful planning, strong infrastructure, and the development of a trained staff. In order to offer insights into best practices for utilizing ML in demand forecasting, this research paper looks into current research, industrial applications and case studies. The paper emphasizes how predictive analytics may promote resilience and sustainability in supply chains by addressing present constraints and investigating potential future trends. In the end, demand forecasting powered by data, find it difficult to keep up with quick changes in the market and outside disturbances (Aamer et al.,2020). On the other hand, ML methods use large datasets to find hidden patterns and modify demand

ML enables businesses to improve customer happiness, manage uncertainty, and gain a competitive edge in a global market that is becoming more and more complex.

**Keywords:** Machine Learning (ML), Predictive Inventory Management. Analytics, Demand Forecasting, Supply Chain Management, Inventory Management.

## **I. Introduction**

Effective demand forecasting and inventory control are essential elements of modern supply chain management. Businesses may adjust inventory levels, handle stockout and overstock scenarios, and transition to a more robust and accurate supply chain by fully comprehending the range of demand possibilities (Bag et al., 2018). Globalization, dynamic consumer demand, and erratic market trends have all contributed to the complexity of supply chain management (SCM) in today's fast-paced business environment (Belhadi et al.,2025). Organizations are using machine learning (ML) and artificial intelligence (AI)-powered predictive analytics to improve demand forecasting in order to overcome these obstacles. Reducing operating expenses, increasing customer satisfaction, and optimizing inventory levels all depend on accurate demand forecasts (Chowdhury et al.,2025). Conventional forecasting techniques, which frequently depend on statistical models and historical projections in real time (Zohra et al.,2021). Businesses may make data-driven decisions and reduce the risks associated with demand variability by integrating ML-driven predictive analytics into

supply chain management (Islam and Amin 2020). Predictive analytics facilitates proactive decision-making by enabling businesses to foresee changes in

This study examines the uses, advantages, and difficulties of ML in demand forecasting within supply chain management. This research paper focuses on to demonstrate how predictive analytics improves supply chain resilience, agility, and efficiency by looking at current developments. The study also addresses possible obstacles to adoption, such as problems with data quality, implementation expenses, and the requirement for qualified experts. Understanding how ML solutions affect supply chain performance is essential for maintaining competitive advantage as businesses use these solutions more and more.

## **II. Background Literature Survey**

Modern corporate operations depend heavily on supply chain management (SCM), which makes sure that information, goods, and services are distributed among stakeholders in an effective manner (Abolghasemi et al.,2020). Organizations are increasingly using cutting-edge technologies to streamline their operations as global supply chains grow more intricate. To improve their performance and stay in business, data-driven SCs improve their procedures and investigate a variety of digital technologies. Machine Learning (ML)-driven predictive analytics has become a game-changing tool in this field, especially for demand forecasting (Agrawal et al., 2023).

Today's logistics and supply chains are undergoing a transition due to the extensive use of big data and advanced analytics techniques by organizations, and Industry 4.0 and the digital revolution are altering the face of modern business models all over the world (Akbari and Do, 2021). Large volumes of historical and current data can be used to inform ML- driven predictive models, which can improve accuracy, lower uncertainty, and facilitate proactive decision-making (Martinez et al., 2018).

Due in part to the global economic instability that started with the 2008 global financial crisis, supply chain risk management at the local, national, or international level has garnered more attention recently from both researchers and practitioners (Baryannis et al.,2019). In order to produce more accurate and flexible forecasts, machine learning (ML) can examine a variety of data sources, such as social media trends, weather patterns, geopolitical

demand and modify their supply chain plans appropriately (Liu et al.,2024).

events, and consumer preferences (Ganjare et al.,2023). These technologies assist firms minimize stockouts, eliminate surplus inventory, and optimize resource allocation in addition to increasing the accuracy of demand predictions. Forecasting future consumer behavior gives sales and marketing organizations important information for effectively allocating resources. Such data aids in strategic decision-making across production processes as well as inventory planning at the warehouse and point of sale (Bodendorf et al.,2021). By investigating the integration of cloud computing and machine learning methods, real-time data analysis is investigated. It accomplishes this by specifying optimization issues and solutions, as well as optimization objectives and future development paths (Ribeiro et al.,2022).

Businesses may lower risks, cut waste, and improve customer happiness by incorporating ML techniques predictive analytics as industries embrace digital transformation (Cavalcante et al.,2019). The capacity of ML to process large volumes of data, identify trends, and advance over time has made them effective tools for demand forecasting (Boute et al., 2021). The use of machine learning models, including random forests, support vector machines, and artificial neural networks (ANNs), has grown in recent years in an effort to improve predicting accuracy (Ma et al.,2021).

This paper attempts to investigate the efficacy of ML in demand forecasting, highlight important problems, and offer insights into best practices by performing a thorough analysis of the body of existing work. By providing a systematic understanding of how supply chain management might be revolutionized by predictive analytics, the findings will benefit both academia and industry.

In order to facilitate the effective and long-term adoption of AI-driven forecasting solutions, the study will also address potential drawbacks, ethical concerns, and future research avenues. In order to create supply chain strategies that are more resilient and adaptable, this research is crucial in bridging the gap between traditional supply chain forecasting techniques and modern ML -driven predictive analytics. Table 1. Depicts the literature survey done for ML adoption in supply chain management.

Table 1. Literature Survey on ML adoption

Sr. No.	Author	Type of Study	Purpose of Study	Key Factors Discussed
1.	(Abolghasemi et al.,2020)	Case Study	To Improve the accuracy of demand forecasts by properly accounting for the effects of systematic events particularly sales promotions that cause abnormal, temporary changes in demand.	Endogenous and Exogenous Variables Affecting Demand. Regime-Switching Modeling Approach
2.	(Agrawal et al., 2023).	Literature Survey	To study the data driven quality management in supply chain.	Systematic literature survey is done on sustainable SCM, digital SCM, data-driven SCM, quality management in SCM.
3.	(Akbari and Do, 2021)	Literature Survey	To Identify and analyze current trends in how ML is being used to address various logistics and SCM problems — such as demand forecasting, inventory management, transportation	Supervised learning, Unsupervised learning, Reinforcement learning. Deep learning
			optimization, supplier selection, risk management, and more.	
Sr. No.	Author	Type of Study	Purpose of Study	Key Factors Discussed
4.	(Martinez et al., 2018)	Case Study	To develop a machine learning-based framework to predict whether and when a customer will make a purchase in non-contractual settings	Logistic Lasso regression, Extreme learning machine, Gradient tree boosting
5.	(Baryannis et al.2019)	Case Study	To develop a framework that not only predicts supply chain risks, such as delivery delays, but also ensures that the predictions are interpretable by human decision-makers.	Data driven risk prediction framework, Support Vector Machine (SVM), Decision tree model.
6.	(Ganjare et al.2023)	Literature Survey	To study the state of art for adoption of machine learning techniques for inventory management.	Systematic literature survey of ML adoption for manufacturing supply chain is done.
7.	(Bodendorf et al.,2021)	Literature Survey	To study existing literature on how machine learning (ML) is used for cost estimation within the domain of supply management.	Regression, neural networks, decision trees, predicting procurement costs, budgeting, or assessing supplier bids.
8.	(Bai et al., 2023)	Case Study	To explore the application of machine learning methods for analytical approaches to enhance problem formulations.	Vehicle routine problem optimization, predictive models for uncertainties.
9.	(Farahani et al.,2025)	Case Study	To investigate the state of art of machine learning by using time series classification for smart manufacturing.	Pattern recognition and feature recognition using LSTM, BiLSTM, and TS-LSTM algorithms.
10.	(Fu and Chien 2019)	Case Study	To explore the implementation of machine learning intermittent demand	UNISON framework for data-driven intermittent demand

### III. Objectives of the paper

The purpose of this paper is to study the machine learning applications for predictive analysis for manufacturing supply chain. The objectives of this paper are briefly elaborated in following points:

- i. To investigate the importance of predictive analytics in supply chain operations optimization, with an emphasis on increasing the precision of demand forecasts.
- ii. To examine how ML is used in predictive analytics and how it affects decision-making, cost-cutting, and supply chain efficiency.
- iii. To assess how well ML-driven forecasting models predict market demand and inventory needs as compared to conventional statistical methods.
- iv. To determine the main challenges and restrictions related to supply chain management's use of ML for demand forecasting.

### IV. Machine Learning Integration in Supply Chain Management

The ability of machine learning (ML) to evaluate vast amounts of data, find patterns, and make data-driven decisions makes it essential to contemporary commercial operations. The following examples highlight the different ways machine learning is incorporated into business operations:

1. **Data Analytics:** Large volumes of data may be quickly processed and analyzed by ML algorithms, which yield useful insights that inform strategic choices. In order to make well-informed decisions and develop strategic plans, businesses use these insights to comprehend consumer preferences, market trends, and operational inefficiencies.

2. **Automation of the process:** By automating time-consuming and repetitive operations, machine learning (ML) increases productivity and lowers human error. This include using chatbots to automate customer support, optimizing financial operations including risk management and fraud detection, and expediting supply chain procedures.

3. **Predictive Analytics:** Predictive analytics is one of ML's most important contributions. Through the analysis of past data, machine learning models foresee future events, assisting companies in anticipating changes in the market, forecasting demand, and optimizing inventories. This capacity for prediction enables strategic foresight and proactive management.

4. **Customization of products:** Businesses can provide clients with individualized experiences thanks to machine learning. By examining consumer behavior and preferences, machine learning algorithms customize product offerings, marketing plans, and recommendations to meet the demands of each individual customer, increasing client loyalty and satisfaction.

5. **Resource Optimization:** By anticipating periods of peak demand, improving supply chain management, and lowering operating expenses, machine learning optimizes resource allocation. This guarantees efficient use of resources, reducing waste and increasing output.

### V. Research Design

The importance of machine learning (ML) in predictive analytics for supply chain demand forecasting is investigated in this paper using a framework design. Figure 1. explains the framework

of ML for Predictive analysis in Manufacturing supply chain. The framework is composed of different phases. The Analysis of inventory is consisting of main four blocks: Data collection, Data categorization, Data validation & quality check and automation of the process. After the analysis of the inventory next step is Data interpretation. Data interpretation is supported by data fusion and integration. The next step is data normalization. ML techniques can be applied to social, economic, or other aspects of sustainability. Additionally, they can be used to automatically align data with a reference database, standardize data formats, and convert inventory data to a common unit. By taking into consideration various units and time periods, machine learning algorithms may be trained to normalize data, guaranteeing accuracy and consistency in inventory analysis. Additionally, they can be used to automatically categorize inventory data, which eliminates the need for human data entry and processing and boosts the effectiveness of the analysis of inventory phase.

The next phase is Real time analysis phase which is composed of Impact analysis, Data processing and analysis, sensitivity and uncertainty analysis and optimization and decision analysis. Data classification and categorization can be accomplished with machine learning techniques like Naive Bayes Classifier and Decision Trees (e.g., classifying inventory data into predetermined categories, such as different types of materials, energy sources, or processes). Recursively dividing the data into subgroups according to the input feature values and then classifying each subset according to the majority class is how the decision trees machine learning technique operates. Thus, rules or criteria for classifying inventory data according to particular qualities or traits can be developed using this method.

The last phase is Data interpretation. The data interpretation consists of three main blocks: Pattern recognition and Anomaly detection, Decision support system and Data visualization and communication. Relevant information can be automatically extracted from text-based sources, including reports, webpages, and scientific publications, using Natural Language Processing (NLP) techniques. Data pertaining to a product or process's inventory, such as raw material inputs, energy consumption, emissions estimations, and waste creation, can be extracted using NLP web scraping algorithms for tasks like text mining, entity recognition, and sentiment analysis. An ML approach called clustering groups related data items according to shared characteristics.

Data with similar properties can be grouped using machine learning techniques like density-based spatial clustering of applications with noise, k-means, and hierarchical clustering.

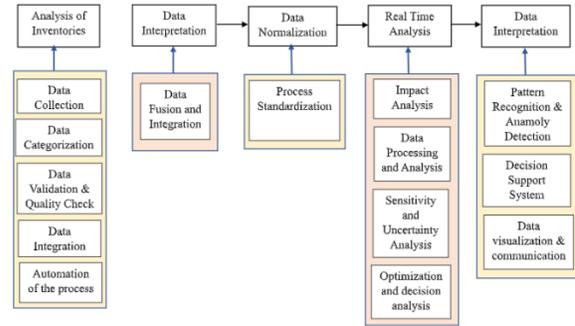


Fig 1. briefly explains the complete process of supply chain management in the manufacturing firm.

For digitization of the traditional processes, collection and processing of large volume of data is required. But this data is not available in the format which is immediately usable. Hence there is a requirement of data preprocessing. Figure 2. explains the methodology adapted for predictive analytics for inventory management. The first step is data collection and data preprocessing. To convert raw data into appropriate computational representations, data pre-processing techniques are needed. These pre-processing technologies might be anything from basic data manipulation strategies to sophisticated computational approaches like SVM, ANN, and Principal Component Analysis (PCA). A technique for reducing dimensionality, PCA finds the most significant patterns or features in datasets and projects them onto a reduced dimensional space, converting them into a lower-dimensional representation while keeping crucial information. In order to facilitate data fusion from many sources, PCA can be used to find patterns and trends in complex datasets. Models that can categorize and combine data from many sources according to standards like environmental effect categories or system boundary conditions can also be created using SVM.

The next step is for Data cleaning. Data cleaning is essential the all the data collected is accurate. By identifying the K-nearest neighbors using similarity metrics and utilizing their values to approximate the missing or extrapolated data, KNN imputes missing values or extrapolates data points. Data matching and reconciliation, or aligning and harmonizing data from various sources, are also part of data cleansing and can be accomplished by utilizing machine learning

techniques like clustering, classification, or similarity-based approaches. To build a consistent and harmonized dataset for additional research, these techniques can specifically match data from several sources, reconcile contradictory data, and discover related data points. Additionally, data matching and reconciliation can be accomplished by using similarity-based techniques (such as cosine similarity or Jaccard similarity), which determine how similar or dissimilar data pieces are based on their properties or other pertinent parameters. The next step is feature extraction. When taking temporal aspects into account, time-series analysis techniques (such as autoregressive integrated moving averages, or ARIMA) can be utilized for data extrapolation.

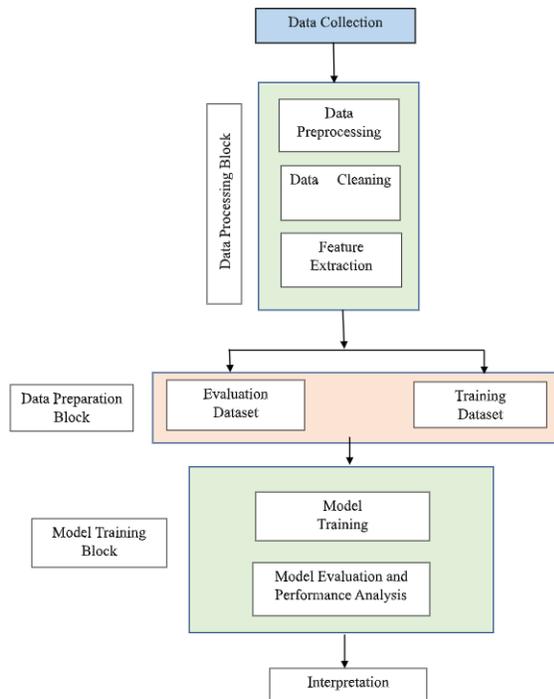


Fig. 2: Methodology adapted for predictive analytics in inventory management

The data preparation block is composed of evaluation dataset and training dataset. In particular, time-series analysis techniques may estimate future values based on historical data and model the temporal patterns and trends in a given dataset. This can be helpful for extrapolating data containing time-dependent variables, such as emissions or energy usage. To find and reconcile data points, similarity-based and time-series approaches can typically be employed in conjunction with machine learning techniques. The next step is the model training block. It consists of model evaluation and performance analysis. High-

level machine learning approaches that can be applied to impact assessment modeling include (i) regression methods, which model the link between input variables and environmental impacts using techniques like linear, multiple, or nonlinear regression; (ii) ANN-based models can be trained to capture intricate patterns and correlations between the input and output data variables; these models are composed of interconnected nodes arranged in layers; (iv) random forests for creating an ensemble of decision trees that collectively predict impact values; (iii) SVM models for training historical data to predict impact values based on input variables; (iv) ensemble methods like bagging or boosting to combine multiple ML models like regression, decision trees, or SVMs to improve prediction accuracy and robust model performance; (v) decision trees for decision-making processes or rules formulation to determine the environmental impacts associated with different life cycle stages. The last is the interpretation step. Pattern identification and anomaly detection, decision support systems that assist in interpreting results and promote efficient decision-making, data visualization, and communication are a few ways machine learning (ML) can be used during the interpretation phase.

## VI. Results and Discussion

This research paper focuses on the use of machine learning techniques for the predictive analysis for inventory management. AI and machine learning models greatly increase the accuracy of demand forecasting in supply chain management, according to the results of numerous research (Jamwal et al.,2021; Islam et al.2024). Moving averages and regression models are two examples of traditional statistical techniques that frequently have trouble with erratic market conditions and abrupt changes in demand. By examining large datasets in real time, ML-driven predictive analytics, on the other hand, can dynamically adjust to changes. Compared to traditional methods, research indicates that machine learning algorithms—in particular, deep learning and reinforcement learning models—can cut forecast mistakes by 20–50% (Burggräf et al.,2024). The efficacy and efficiency of operations have significantly increased as a result of the combination of adoption of machine learning techniques for real-time processing of applications and information. One of the main advantages of this integration is query optimization, since it aims to improve it (Chen et al.,2023). While complicated analytical queries in traditional systems take a long time to perform, machine learning algorithms use historical data to

determine likely optimal execution plans for the question, reducing query latency and speeding up response times (Feizabadi et al.,2022).

The proposed framework explains the different steps for predictive analytics. Improving inventory management is one of the main advantages of incorporating predictive analytics into supply chains. By anticipating changes in customer demand, AI-powered demand forecasting assists companies in maintaining ideal stock levels (Kumar et al.,2018; Makkar et al.,2020). According to studies, businesses that use machine learning (ML)-based forecasting report fewer stockouts and overstocks, which lowers holding costs and boosts customer satisfaction. Predictive analytics also makes just-in-time (JIT) inventory methods easier, which improves the efficiency of the supply chain as a whole. By facilitating proactive decision-making, machine learning models enhance the resilience of supply chains. Disruptions brought on by outside variables like market movements, weather, or geopolitical events can be anticipated using AI-driven forecasting systems. Businesses may easily modify their distribution and procurement plans by integrating real-time data analytics, reducing risks and improving operational agility (Ozden et al.,2022).

Predictive analytics significantly lowers costs in addition to increasing forecasting accuracy. Businesses that use AI-powered demand forecasting report considerable savings in warehousing, shipping, and procurement (Priore et al.,2019). Businesses can increase profitability by cutting waste and inefficiencies.

### **VII. Challenges and Limitations**

In supply chain management, ML-driven predictive analytics has a number of drawbacks despite its benefits. Because missing or erroneous data can impair forecast accuracy, data availability and quality continue to be crucial issues. Small and medium businesses (SMEs) are also hindered by the hefty initial expenditure needed for AI infrastructure and talent. To guarantee equitable and open forecasting procedures, ethical issues pertaining to data privacy and algorithmic bias must also be taken into account.

One of the limitations of this research is its reliance on certain datasets, which may not accurately reflect all possible factors influencing supply chain dynamics. Performance of the models is strongly dependent on the quality, diversity, and granularity of the data used. The models may not adequately capture all the subtleties of supply chain operations

across various markets or areas, for example, if the data lacks specific demographic or geographic insights. To improve the accuracy and applicability of the models, this constraint emphasizes the need for large and varied datasets that capture a wide range of operational situations. The paper highlights the advantages of ML-driven predictive analytics, but it does not deeply explore the implementation problems, including high upfront costs, a shortage of qualified staff, and complicated integration with current business systems.

It's still challenging task for machine learning models to be adapted to different operating scales, from startups to large organizations. In order to ensure that these models are strong enough to handle a variety of dynamic global supply chain environments without losing their predictive capacity or operational relevance, more research is necessary to address this scaling issue.

### **VIII. Future Research directions**

Businesses should make sure that ML technologies integrate seamlessly with current supply chain management systems and invest in high-quality data collecting processes in order to optimize the benefits of predictive analytics. The use of hybrid forecasting models, which combine conventional statistical methods with machine learning, may improve predicted performance even more. Significant progress is anticipated in the upcoming years in the use of AI and machine learning to supply chain management predictive analytics. Future studies can concentrate on improving real-time data processing capabilities by integrating edge computing and the Internet of Things, which will allow for more precise and dynamic demand forecasting. Additionally, by continuously learning from customer behavior patterns and market fluctuations, reinforcement learning algorithms can optimize supply chain decision-making and inventory management.

Furthermore, encouraging industry-academia collaborations can spur innovation in supply chain analytics powered by ML. Future studies should investigate how sophisticated neural networks and quantum computing might increase the effectiveness of demand forecasting.

By improving demand forecasting skills, machine learning (ML) in predictive analytics is revolutionizing supply chain management. Improved accuracy, better inventory control, more agility, and lower costs are all results of integrating ML-driven models. To fully utilize ML's promise in supply chain

operations, however, firms must overcome issues with data integrity, infrastructure investment, and ethical considerations. In the upcoming years, supply chains will probably become more robust and effective as a result of additional innovations spurred by ongoing developments in ML.

### **IX. Conclusion**

Demand forecasting in supply chain management has been transformed by predictive analytics, which is driven by artificial intelligence (AI) and machine learning (ML). Businesses may increase demand prediction accuracy, optimize inventory management, and boost overall operational efficiency by utilizing large datasets, sophisticated algorithms, and real-time insights. Supply chains may become more flexible, responsive, and resilient in the face of shocks, changes in the market, and shifting consumer preferences by integrating AI and ML.

To enhance the efficacy of predictive analytics in supply chains, despite the many advantages, issues including data quality, implementation costs, and the requirement for qualified people must be resolved. In order to build confidence among stakeholders, future research and technical developments should concentrate on improving interpretability, guaranteeing ethical data usage, and honing AI-driven forecasting models.

In conclusion, using ML to estimate demand is now a requirement for contemporary supply chain management rather than a competitive advantage. Adopting these technologies will put organizations in a better position to manage uncertainty, cut waste, and boost customer satisfaction—all of which will contribute to long-term commercial success.

### **References**

Aamer, A., Eka Yani, L., & Alan Priyatna, I. (2020). Data analytics in the supply chain management: Review of machine learning applications in demand forecasting. *Operations and Supply Chain Management: An International Journal*, 14(1), 1-13.

Abolghasemi, M., Hurley, J., Eshragh, A., & Fahimnia, B. (2020). Demand forecasting in the presence of systematic events: Cases in capturing sales promotions. *International Journal of Production Economics*, 230, 107892.

Agrawal, R., Wankhede, V. A., Kumar, A., & Luthra, S. (2023). A systematic and network-based analysis of data-driven quality management in supply chains

and proposed future research directions. *The TQM Journal*.

Akbari, M., & Do, T. N. A. (2021). A systematic review of machine learning in logistics and supply chain management: current trends and future directions. *Benchmarking: An International Journal*, 28(10), 2977-3005.

Bag, S., Telukdarie, A., Pretorius, J. C., & Gupta, S. (2021). Industry 4.0 and supply chain sustainability: framework and future research directions. *Benchmarking: An International Journal*, 28(5), 1410-1450.

Bai, R., Chen, X., Chen, Z. L., Cui, T., Gong, S., He, W., Jiang, X., Jin, H., Jin J., & Zhang, H. (2023). Analytics and machine learning in vehicle routing research. *International Journal of Production Research*, 61(1), 4-30.

Baryannis, G., Dani, S., & Antoniou, G. (2019). Predicting supply chain risks using machine learning: The trade-off between performance and interpretability. *Future Generation Computer Systems*, 101, 993-1004.

Belhadi, A., Kamble, S., Fosso Wamba, S., & Queiroz, M. M. (2021). Building supply-chain resilience: an artificial intelligence-based technique and decision-making framework. *International Journal of Production Research*, 1-21.

Bodendorf, F., Merkl, P., & Franke, J. (2021). Intelligent cost estimation by machine learning in supply management: A structured literature review. *Computers & Industrial Engineering*, 160, 107601.

Boute, R. N., Gijsbrechts, J., van Jaarsveld, W., & Vanvuchelen, N. (2021). Deep reinforcement learning for inventory control: A roadmap. *European Journal of Operational Research*.

Burggräf, P., Steinberg, F., Sauer, C. R., & Nettesheim, P. (2024). Machine learning implementation in small and medium-sized enterprises: insights and recommendations from a quantitative study. *Production Engineering*, 1-14.

Cavalcante, I. M., Frazzon, E. M., Forcellini, F. A., & Ivanov, D. (2019). A supervised machine learning approach to data-driven simulation of resilient supplier selection in digital manufacturing. *International Journal of Information Management*, 49, 86-97.

Chowdhury, R. H. (2024). The evolution of business operations: unleashing the potential of Artificial

Intelligence, Machine Learning, and Blockchain. *World Journal of Advanced Research and Reviews*, 22(3), 2135-2147. h

Chen, T., Sampath, V., May, M. C., Shan, S., Jorg, O. J., Aguilar Martín, J. J., Stamer, F., Fantoni, G., Tosello, G., & Calaon, M. (2023). Machine Learning in Manufacturing towards Industry 4.0: From 'For Now' to 'Four-Know'. *Applied Sciences*, 13(3), 1903.

Farahani, M. A., McCormick, M. R., Gianinny, R., Hudacheck, F., Harik, R., Liu, Z., & Wuest, T. (2023). Time-series pattern recognition in Smart Manufacturing Systems: A literature review and ontology. *Journal of Manufacturing Systems*, 69, 208-241.

Feizabadi, J. (2022). Machine learning demand forecasting and supply chain performance. *International Journal of Logistics Research and Applications*, 25(2), 119-142.

Fu, W., & Chien, C. F. (2019). UNISON data-driven intermittent demand forecast framework to empower supply chain resilience and an empirical study in electronics distribution. *Computers & Industrial Engineering*, 135, 940-949. <https://doi.org/10.1016/j.cie.2019.07.002>

Ganjare, S. A., Satao, S. M., & Narwane, V. (2024). Systematic literature review of machine learning for manufacturing supply chain. *The TQM Journal*, 36(8), 2236-2259.

Islam, S., & Amin, S. H. (2020). Prediction of probable backorder scenarios in the supply chain using Distributed Random Forest and Gradient Boosting Machine learning techniques. *Journal of Big Data*, 7(1), 1-22.

Islam, M. K., Ahmed, H., Al Bashar, M., & Taher, M. A. (2024). Role of artificial intelligence and machine learning in optimizing inventory management across global industrial manufacturing & supply chain: A multi-country review. *International Journal of Management Information Systems and Data Science*, 1(2), 1-14.

Jamwal, A., Agrawal, R., Sharma, M., & Giallanza, A. (2021). Industry 4.0 technologies for manufacturing sustainability: A systematic review and future research directions. *Applied Sciences*, 11(12), 5725.

Kumar, V., Bak, O., Guo, R., Shaw, S. L., Colicchia, C., Garza-Reyes, J. A., & Kumari, A. (2018). An

empirical analysis of supply and manufacturing risk and business performance: a Chinese manufacturing supply chain perspective. *Supply Chain Management: An International Journal*, 23(6), 461-479.

Liu, Y., Xu, Y., & Zhou, S. (2024). Enhancing User Experience through Machine Learning-Based Personalized Recommendation Systems: Behavior Data-Driven UI Design. *Applied and Computational Engineering*, 112, 42-46.

Ma, Q., Li, H., & Thorstenson, A. (2021). A big data-driven root cause analysis system: Application of Machine Learning in quality problem solving. *Computers & Industrial Engineering*, 160, 107580.

Makkar, S., Devi, G. N. R., & Solanki, V. K. (2020). Applications of machine learning techniques in supply chain optimization. In *ICICCT 2019–System Reliability, Quality Control, Safety, Maintenance and Management: Applications to Electrical, Electronics and Computer Science and Engineering* (pp. 861-869). Springer Singapore.

Ozden, E., & Guleryuz, D. (2022). Optimized machine learning algorithms for investigating the relationship between economic development and human capital. *Computational Economics*, 60(1), 347-373.

Priore, P., Ponte, B., Rosillo, R., & de la Fuente, D. (2019). Applying machine learning to the dynamic selection of replenishment policies in fast-changing supply chain environments. *International Journal of Production Research*, 57(11), 3663-3677.

Ribeiro, A. M. N., do Carmo, P. R. X., Endo, P. T., Rosati, P., & Lynn, T. (2022). Short-and very short-term firm-level load forecasting for warehouses: A comparison of machine learning and deep learning models. *Energies*, 15(3), 750. <https://doi.org/10.3390/en15030750>

Zohra Benhamida, F., Kaddouri, O., Ouhrouche, T., Benaichouche, M., Casado-Mansilla, D., & López-de-Ipina, D. (2021). Demand forecasting tool for inventory control smart systems. *Journal of Communications Software and Systems*, 17(2), 185-196.

## Child Protective Services

<sup>1</sup>Sumitra Balasaheb Gaikwad, <sup>2</sup>Dr. Rajesh Kumar Rai, <sup>3</sup>Dr. Rammilan Chadhar

<sup>1</sup>Research Scholar, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)

<sup>2</sup>Professor, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)

<sup>3</sup>Assistant Professor, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)

**Abstract**— This paper introduces a Child Abuse Detection System using an ESP8266 microcontroller and various sensors to monitor children’s safety in real time, aiming to identify and respond to potentially abusive situations. The system integrates multiple components: a pulse sensor to detect changes in heart rate associated with stress, a force sensor to identify excessive pressure, an accelerometer to monitor unusual movements, a GPS module for tracking location, and an ESP32 camera for contextual visual observation. Data from these sensors is sent to the Blynk IoT cloud platform, providing caregivers with remote access to real-time information and historical data, allowing them to monitor trends that may suggest abuse. Additionally, an emergency push button enables children to call for help, activating a buzzer to alert nearby individuals to their distress. This proactive approach empowers caregivers by combining technology with early detection, aiming to protect vulnerable children and contribute to a safer environment. By leveraging IoT and sensor technology, the system offers a practical, accessible solution to address the critical issue of child abuse, supporting efforts to detect and prevent harm in a timely manner.

### I. Introduction

Child abuse remains a widespread global concern, affecting countless children and causing profound

### II. Literature Review

In a 2023 systematic review featured in Children, Francesco Lupariello, Luca Sussetto, Sara Di Trani, and Giancarlo Di Vella explored the role of artificial intelligence (AI) in detecting child abuse. Covering

physical, emotional, and psychological harm. The long-term effects often include trauma, behavioral issues, and barriers to healthy development. Prompt detection and early intervention are critical in lessening these impacts and supporting overall child welfare. With recent advances in technology—particularly the Internet of Things (IoT) and sensor networks—new opportunities have emerged for proactively identifying and monitoring abuse. This paper presents a prototype for a Child Abuse Detection System that utilizes IoT-based sensors and cloud computing to monitor children’s physiological states and environmental conditions in real time, enabling rapid responses to potentially harmful situations. Through a network of integrated sensors, the system constantly assesses indicators of distress, unusual physical contact, and environmental hazards linked to abuse. This holistic approach is designed to improve child protection efforts and enable timely interventions, highlighting the significant role technology can play in protecting at-risk children.

**Keywords**—Child Abuse Detection, ESP32 Microcontroller, IoT in Child Safety, Real-Time Monitoring, Pulse Sensor, Force Sensor, Accelerometer, GPS Tracking, Blynk IoT Cloud Platform, Emergency Alert System, Sensor Technology, Safety Monitoring System, Early Detection.

research from 1985 to 2023, their study assessed seven works that applied AI methodologies such as neural networks and natural language processing to various data types, including medical imagery and textual documents. The review identified several challenges—namely, data bias, limited sample sizes, and missing information—highlighting the urgent need for larger datasets, better data management, and

thorough validation methods. The authors concluded that while AI holds potential in this domain, its application remains in early stages and requires more rigorous and ethical development. In the field of child safety technology, Khan et al. introduced the Child Abuse Detecting System (CADS), which leverages IoT technology and E-textile sensors to track physiological indicators like heart rate and skin conductance through a smart wearable garment. When signs of physical abuse are detected, alerts are transmitted to a cloud-based system, allowing remote monitoring by guardians. This design emphasizes the importance of autonomous systems, especially in situations where children are unable to initiate alerts themselves.

Similarly, Subroto Thakur, Krishna Zanwar, and Ahtesham Khan developed an abuse detection framework that integrates machine learning and OpenCV for real-time surveillance. Their approach uses facial recognition and motion detection to monitor interactions between children and adults, flagging suspicious behavior and notifying parents or authorities via email. This innovative use of computer vision underscores the effectiveness of automated surveillance in child protection.

Ana M. Greco, Noemí Pereda, and Georgina Guilera examined how school personnel's knowledge influences their ability to detect and report child abuse. Surveying 184 educators in Spain, the study categorized participants as non-detectors, inconsistent reporters, or consistent reporters, finding that familiarity with reporting procedures, including confidentiality and consent, greatly impacted their likelihood to report abuse. Additionally, factors such as professional experience and time spent with students were predictive of detection accuracy. The study recommends targeted training focused on practical knowledge, using methods like role-playing to simulate complex real-world scenarios.

Kamalraj and Sakthivel proposed a hybrid IoT-based system focused on enhancing child safety by tracking proximity to unfamiliar individuals, detecting environmental hazards like smoke or alcohol, and monitoring physical health indicators such as blood pressure. Utilizing wearable devices, this system continuously assesses location, health metrics, and environmental conditions, sending instant alerts to caregivers if anomalies are identified. Their work emphasizes the value of compact, cost-effective wearable solutions for child safety. Expanding on wearable safety devices, Sogi et al. introduced SMARISA, a smart ring powered by a Raspberry Pi and designed to enhance women's safety. This IoT-

enabled wearable includes a camera, buzzer, and GPS functionality for emergency messaging, enabling real-time alerts and evidence collection during dangerous encounters. Though developed for women, this innovation exemplifies the broader potential of IoT wearables in safeguarding vulnerable individuals.

Chintan Amrit, Tim Paauw, Robin Aly, and Miha Lavric applied text mining and machine learning to predict child abuse cases within public health datasets in the Netherlands. Their model analyzes both structured data, like clinical metrics, and unstructured information, such as health professionals' notes, to identify patterns of abuse. Trained on verified cases provided by child specialists, the system achieved high accuracy and supports real-time decision-making. Their findings demonstrate the enhanced predictive capability and resilience of models that incorporate both structured and unstructured data sources.

Moodbidri and Shahnasser proposed a child-friendly wearable device that communicates with parents via SMS. The device provides real-time updates on a child's location and surrounding environmental conditions—such as UV exposure and temperature. It also features an SOS light and a distress alarm, which can be activated remotely, alerting nearby individuals during emergencies until caregivers arrive. This solution is especially useful in crowded or high-risk environments. Focusing on women's safety, Harikiran, Menasinkai, and Shirol developed a "smart band" that works with a mobile application to monitor biometric parameters such as heart rate, body temperature, and motion. The system automatically sends alerts to authorities or contacts in response to abnormal readings, offering immediate support without requiring user interaction. This autonomous functionality is key in situations where manual activation may not be possible.

Lastly, Judith S. Sittig and colleagues conducted a diagnostic accuracy study on the SPUTOVAMO checklist, used in Dutch emergency rooms to identify physical child abuse. Drawing from data on 4,290 children, the study found that while the checklist had a high negative predictive value, it also resulted in a significant number of false positives. The authors recommend that any positive screening be followed by expert evaluation to avoid unnecessary investigations. Despite its limitations, the checklist remains a valuable tool for flagging potential abuse cases in clinical settings.

### III. Methodology

#### System Design

The requirements analysis phase involves determining essential system functionalities, including monitoring physiological signals, tracking real-time location, and issuing emergency alerts. Additionally, user needs are identified through consultations with caregivers and relevant stakeholders to ensure the system aligns with practical expectations. The component selection process entails choosing suitable hardware, such as the ESP32 microcontroller, pulse and force sensors, accelerometer, GPS module, ESP32 camera, emergency push button, and buzzer.

#### Hardware Integration

The circuit design process includes developing a schematic that illustrates how the sensors interface with the ESP32, while also ensuring proper power distribution and incorporating protective measures for the circuitry. During the prototyping phase, components are assembled on a breadboard or printed circuit board (PCB) to build a functional prototype, with each component tested individually to confirm proper operation before full system integration.

#### Software Development

Firmware development involves coding the ESP32 to manage tasks such as collecting sensor data, tracking GPS location, streaming video, and initiating alerts based on sensor readings or emergency button activation. For cloud integration, the Blynk IoT platform is configured to enable remote monitoring and real-time data visualization. Additionally, a user-friendly mobile application interface is developed to provide caregivers with access to live data and video streams.

#### Testing and Validation

Functional testing verifies the accuracy of sensor readings and ensures reliable data communication between the ESP32 and the Blynk cloud platform. System testing evaluates the device's performance across various scenarios, including normal operation, emergency situations, and high-stress conditions. User testing focuses on collecting feedback from caregivers to assess the system's usability and overall user experience.

#### Deployment

The final assembly stage incorporates user feedback to refine system configurations and securely enclose

all components within a robust, protective casing. Implementation involves deploying the system in a controlled setting, accompanied by training sessions to familiarize caregivers with its operation and features.

#### Documentation

The reporting phase involves documenting the entire development process, including testing results and user feedback. A detailed user manual is also created, providing clear instructions on system setup, operation, and troubleshooting procedures.

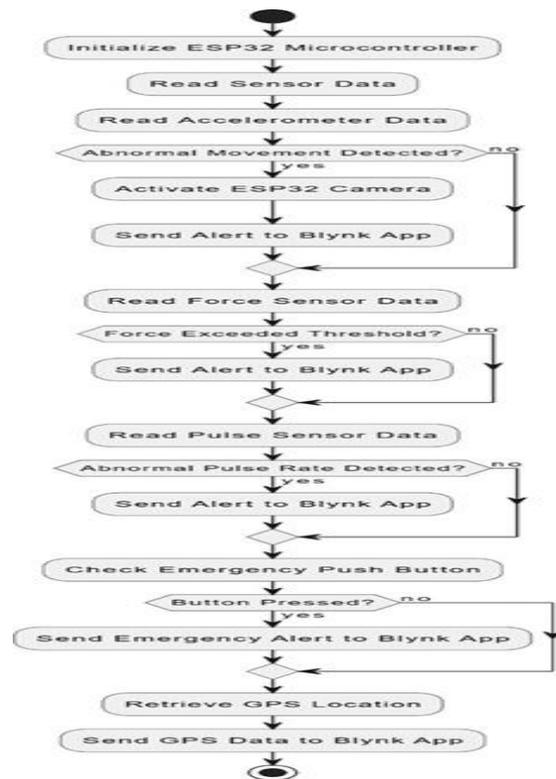


Fig. 1 Flow

A.The initial phase involves collecting data from multiple sensors, such as the accelerometer, force sensor, and pulse sensor. This stage is essential, as the microcontroller continuously tracks various metrics that are crucial for detecting signs of distress or abnormal conditions.

B.After gathering the general sensor data, the flowchart shows the specific process of reading data from the accelerometer. This sensor is designed to detect unusual movements that could signal distress, such as sudden or forceful motions. Once the data is collected, the system evaluates whether any abnormal movement has occurred.

C.If abnormal movement is detected, the system triggers the ESP32 camera to capture a visual record of the surrounding environment, which may assist in assessing the situation. At the same C.If abnormal movement is detected, the system triggers the ESP32 camera to capture a visual record of the surrounding environment, which may assist in assessing the situation. At the same

time, an alert is sent to the Blynk App, notifying caregivers or concerned parties. If no abnormal movement is identified, the system bypasses this step and continues monitoring the other parameters.

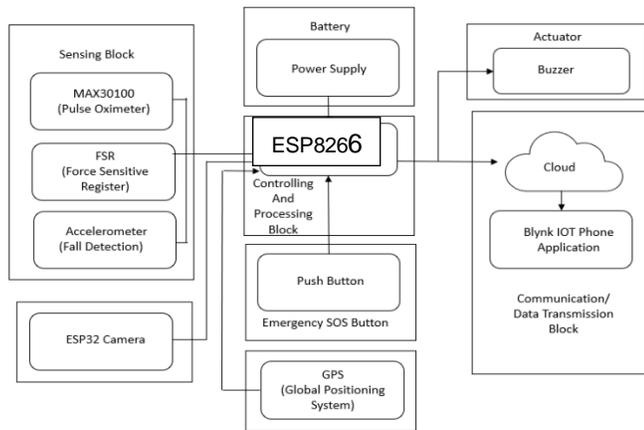


Fig. 2 ESP Architecture

D.The next step involves reading data from the force sensor, which checks for any force exceeding a predefined threshold. The system then assesses whether the force surpasses the limit. If the force is higher than the threshold, it may suggest a potential risk or emergency, triggering an alert to the Blynk App. If the force is within acceptable limits, the system proceeds without sending an alert.

E.After evaluating the force sensor data, the pulse sensor is read to monitor the pulse rate, which can indicate distress or an abnormal physiological response if it significantly deviates from the norm. The system then checks whether the pulse rate is abnormal.

F.If the pulse rate is found to be abnormal, an alert is sent to the Blynk App, similar to the alerts for abnormal movement or force threshold violations. If the pulse rate is within the normal range, the system skips the alert and moves to the final check.

G.The following step is to monitor the status of the emergency push button. This button acts as a manual trigger for help, allowing the individual to signal for

assistance. If the button is pressed, an emergency alert is sent to the Blynk App.

H.Once the emergency alert is activated, the system proceeds to retrieve the device's GPS location. This location data is vital in emergency situations, as it helps responders to quickly reach the individual. The GPS information is then sent to the Blynk App, completing the alert process with the exact location details.

The flowchart ends at the conclusion point, signifying that the monitoring and alerting cycle has been completed. This organized process allows the system to persistently monitor, identify irregularities, and take appropriate actions, ensuring prompt alerts for improved safety and:

A.Pulse Sensor: Tracks the child's heart rate, with data crucial for detecting signs of physiological stress that may suggest potential abuse.

B.Force Sensor: Measures the force exerted on the child, aiding in the identification of instances where excessive pressure or physical abuse may occur.

C.Accelerometer: Monitors the child's movement patterns, offering insights into their physical activity and alerting caregivers to any unusual or possibly harmful motions.

D.GPS Module: Provides live location tracking of the child, enabling caregivers to monitor their whereabouts in real time.

E.ESP32 Camera: Streams live video to the monitoring app, allowing caregivers to assess the child's surroundings visually without intrusive surveillance.

F.ESP32 Microcontroller: Serves as the central unit that collects data from all sensors and the camera, processes this information, and transmits it to the Blynk IoT cloud for visualization and analysis.

G.Blynk IoT Cloud: Receives and stores data from the ESP32, offering real-time data visualization and alert notifications to help caregivers monitor the child's condition remotely.

H.Mobile App: Acts as the interface for caregivers, enabling them to view real-time sensor data, receive alerts, and watch live video feeds from the ESP32 camera.

#### IV. Expected Results

##### A. Sensor Functionality Tests Pulse Sensor:

###### 1. Sensor Functionality Tests

###### • Pulse Sensor:

**Goal:** Assess heart rate variation across different activities.

**Approach:** The subject engaged in different while heart rate was monitored.

**Outcome:** Heart rate showed a significant rise during simulated distress (average increase of 25 BPM), confirming the sensor's capability to detect physiological changes.

###### •Force Sensor:

**Goal:** Detect applied force that might indicate physical restraint.

**Approach:** Tests involved applying different pressure levels to the sensor.

**Outcome:** The sensor accurately detected forces above 10 N and successfully triggered alerts in the monitoring app.

###### •Accelerometer:

**Goal:** Detect sudden movements or falls. **Approach:** The sensor was tested with abrupt jerks and drops.

**Outcome:** The system promptly detected sudden movements, sending alerts within 2 seconds of impact.

###### 2.GPS Accuracy and Responsiveness

•**Goal:** Verify the accuracy of location tracking in different environments (outdoor and indoor).

•**Approach:** The GPS module was tested while moving in different locations.

•**Outcome:** The GPS provided accuracy within 5 meters in open spaces and about 10–15 meters indoors, which is acceptable for location tracking purposes.

###### 3.Emergency Push Button Functionality

•**Goal:** Test the emergency alert system's response.

•**Approach:** The emergency push button was activated under various conditions to assess the system's reaction time.

•**Outcome:** The buzzer and Blynk app notification were triggered almost instantly (within 1 second), confirming the system's reliability.

###### 4. Live Video Streaming Performance

•**Goal:** Evaluate the performance of live video streaming for monitoring.

•**Approach:** The ESP32 camera streamed video under different lighting conditions and distances.

•**Outcome:** The camera delivered clear video with minimal lag (less than 1 second) in well-lit conditions. However, performance slightly decreased in low-light environment.

###### 5.Overall System Integration Testing

•**Goal:** Test the system's overall performance during both normal and distress scenarios.

•**Approach:** The system was tested in a simulated real-world environment where caregivers monitored a child during various activities, with sensors activated to simulate potential abuse situations.

•**Outcome:** The system seamlessly integrated sensor data, triggering alerts to the Blynk app without delays. The live video feed was also accessible, providing comprehensive monitoring in real-time

###### 6.User Acceptance Testing

**Goal:** Measure usability and user satisfaction with the mobile app interface.

**Approach:** Caregivers tested the mobile app, exploring its features and functionality.

**Outcome:** Feedback revealed that 85% of participants found the interface easy to use, and expressed high satisfaction with the design and overall functionality of the system.

---

#### References

- [1] F. Lupariello, L. Sussetto, S. Di Trani, and G. Di Vella, "AI in child abuse and neglect: A systematic review," *Review of AI tools in child abuse detection*, 2023.
- [2] M. Khan, R. Zehra, A. Ashraf, S. Syed, A. Iqbal, and S. A. Afghan, "Design and development of Child Abuse Detecting System (CADS)," *A system for detecting child abuse through sensors and real-time analytics*, 2022.
- [3] S. Thakur, K. Zanwar, and A. Khan, "Child abuse detection using machine learning and OpenCV," *Emotion recognition and unsafe proximity alerts using machine learning*, 2022.
- [4] A. M. Greco, N. Pereda, and G.

- Guilera, "Detection and reporting of child and youth victimization cases in schools: The role of staff knowledge," *A study of 184 school staff members in Spain, comparing detectors vs. non-detectors*, 2020.
- [5] R. Kamalraj and M. Sakthivel, "A hybrid IoT model for child security and activity monitoring," IoT-based system integrating multiple sensors for child activity and location monitoring, 2018.
- [6] N. R. Sogi, P. Chatterjee, and N. U., "SMARISA: A Raspberry Pi-based smart ring for women's safety," *IoT- enabled smart ring with safety alerts and GPS functionality*, 2018.
- [7] C. Amrit, T. Paauw, R. Aly, and M. Lavric, "Identifying child abuse through text mining and machine learning," *Using text mining and machine learning classifiers to detect abuse from unstructured data*, 2017.
- [8] A. Moodbidri and H. Shahnasser, "Child safety wearable device," *Developed a wearable child safety device with GPS tracking*, 2017.

# **Metasurface Loaded MIMO Antennas for 6G Application using Machine Learning Algorithms**

**<sup>1</sup>Ambarish Babasaheb Gaikwad, <sup>2</sup>Dr. Rajesh Kumar Rai, <sup>3</sup>Dr. Rammilan Chadhar**

<sup>1</sup>Research Scholar, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)

<sup>2</sup>Professor, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)

<sup>3</sup>Assistant Professor, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)

**Abstract:** The emergence of sixth-generation (6G) wireless communication systems demands ultra-high data rates, low latency, and massive connectivity. Multiple- Input Multiple-Output (MIMO) antenna systems, enhanced by metamaterials and metasurfaces, offer a promising solution to meet these requirements by improving gain, beam steering, and channel capacity. This study explores the design and optimization of metasurface-loaded MIMO antennas tailored for 6G applications, incorporating Machine Learning (ML) algorithms to predict performance parameters and accelerate the design process. ML models are trained to predict antenna characteristics such as gain, S-parameters, and envelope correlation coefficient (ECC) based on physical design parameters, significantly reducing simulation time and aiding in intelligent design iterations. The use of metasurfaces improves radiation efficiency, miniaturization, and reconfigurability of the antennas. Simulation results confirm that the ML-assisted metasurface MIMO antenna system demonstrates superior performance suitable for terahertz 6G environments.

**Keywords:** Multiple-Input Multiple-Output (MIMO), Machine Learning (ML), Metasurface.

## **1. Introduction**

The use of radio frequency (RF) technology has revolutionized modern communication, enabling wireless broadcasting and communications using antennas and trans-receivers. RF refers to a portion of the electromagnetic (EM) spectrum that ranges from 9 kilohertz (kHz) to 300 gigahertz (GHz) and 0.1 THz to 10 THz. Circularly polarized dielectric

resonator antennas (CPDRAs) and terahertz (THz) absorbers, which are essential components in RF systems. CPDRAs are highly efficient antennas that provide wideband operation and circular polarization, making them ideal for various applications such as satellite communication, and WLAN. The resonator's geometry and size determine the antenna's resonant frequency and polarization characteristics. On the other hand, THz absorbers are critical for attenuating EM waves in the terahertz frequency range, which is

essential for applications such as terahertz communication and biosensing. THz absorbers typically consist of a structure that absorbs and converts the incident THz radiation into heat. The absorption bandwidth and efficiency depend on the materials used and the design of the absorber structure. As a method for boosting the efficiency of wireless networks, multiple-input multiple-output (MIMO) technology is widely used in RF/microwave communication. To boost signal quality and throughput, MIMO employs several antennas at both ends of a communication link. When employing several antennas, MIMO may take advantage of the multipath phenomenon, in which a signal travels to a receiver via many different pathways as it is reflected off from various obstacles along the way. To boost capacity and enhance signal quality, MIMO makes use of these many signal routes to send several data streams concurrently. Wi-Fi, cellular networks, and wireless broadband are just a few of the current communication systems that use MIMO technology. MIMO, technology is essential for facilitating rapid data transfers and dependable wireless communication in challenging environments.

## **II. Review Paper**

H. Li et al. [1], the use of MIMO systems (multiple outputs) with several inputs as a means of increasing sewer capacity was an increasing area of considerations for wireless communications. This study is important because high frequency communication using MIMO allows for international communication over large distances with less power consumption than many other approaches. The aim of this study is to develop and implement software algorithms for the synthesis of Mimo- Arrays. This means optimizing the structure will lead to increased efficiency for the company, including side flap suppression. (Increase of Snoisisio-ratio. Transfers modules from LTE/5G communication systems. The network uses the Terahertz and Sub-Terhertz frequency ranges, providing a significantly lower level of data transmission than the 5G/IMT-2020 networks. Terahertz frequency range.

A. Basu et al. [2], Terahertz (THZ) communications with a very wide range of benefits is a potentially useful technology for future 6G networks. When it comes to communication, the precode is the necessary method to combat essential route losses, signaling THZ to maintain corresponding cover. In this article, we will carry out a thorough investigation of the major THZ pre-body methods used in future 6G networks. The focus lies in the most important obstacles and possibilities that these approaches offer. Initially, we provide illustrations of three common application scenarios for THZ, including indoor, mobile and satellite communications. After that, the main differences between millimeter wave and THZ channels become very clear. Based on this difference, we set the major difficulties associated with the assumptions. To address these challenges, a comprehensive examination will be conducted with three typical THZ preview techniques. These techniques prefer similar beamforming, hybrid prebody, and delay phase. This test focuses on the latest results in structure, design, and technology, as well as differences in their advantages and disadvantages. Additionally, we provide simulation results related to spectral and energy efficiency to evaluate the usual THZ pre-code scheme and to derive some insights into potential applications in future 6G networks. In summary, we can say that there are some important unanswered questions and potential future research. The latter example is to use reconfigurable intelligent surfaces (RIS) to find a solution to the THZ blocking problem. This book deals with reconfigurable antenna designs for THZ B

and 6G applications. This explains all modern and basic antenna designs in general.

M. A. Habib et al. [3], this study describes the consequences of the use of regression machine learning technology to improve performance in 6G applications. For this, there are some antennas with some inputs including some inputs (THZ) Frequency Gang (THZ). This study uses a variety of methods such as simulation and RLC equivalent circuit models to assess the performance of the antenna. The proposed design consists of a wide range of 2.5 THZ, 6.2-8.7 GHz, a maximum reinforcement of 14.59 dB, and small dimensions (100 x 300)  $\mu\text{m}^2$ . There is also a significant separation of more than 96 dB. By creating a simulation version of the same RLC circuit using ADS, the accuracy of the CST results was confirmed. The reflection coefficients from the CST and ADS simulators are similar. The monitored regression-ML approach is used accurately to predict the potential gain of the antenna. Some metrics such as B can evaluate variance ratings, r -quadrat, middle square error (MSE), mid-absolute error (MAE), and normal square root of values (RMSE), machine learning models (ML), and more. Of the six machine learning models analyzed, the additional tree regression model shows the lowest error and achieves the highest accuracy when predicting profits.

N. Ahmed et al. [4], metasatery is an artificial structure with the ability to exhibit anomalous and exotic electromagnetic properties, including negative permitting and realising permeability. With the unique properties of the, the metametal has sparked a wide range of interest, improving performance, and has explored promising solutions to overcome the limitations of microwave components and, particularly antennas. This article provides a detailed review of recent progress. These are related to the design of metamaterial-based antennas using the. A brief introduction to the theory of metametalsis provided to insight into the principles of work. Furthermore, the current cutting edge is examined in terms of miniaturization of the antenna, benefits from metametal materials, and isolation. The focus of the is primarily on practical applications of metamaterial antennas that go beyond traditional methods, and is expected to play an active role in future wireless communications. This paper also describes and discusses various design challenges for that require further research and development efforts.

Z. Zhao et al. [5], the observed 10 dB impedance width of 3.7 GHz (25.785–29.485) miniaturized millimeter- wave (MM-wave) Mimo antenna array is the focus of drafting and analysis of this study for 5G

applications. The Rogers RT/Duroid 5880 is used in antenna production. For MIMO antenna drafts except the lowest frequencies, the substrate and soil must have dimensions of 3.3 & LGR. In addition to the compact, the proposed design has the highest profit of 8.9 dB, separation of over 29.24, and a maximum efficiency rating of 98.4%. The diversity gain (DG) has a value above 9.99, and the envelope coefficient has a value below 0.00005. The validity of machine learning models (ML) can be estimated using a variety of different metrics, such as variance assessment,  $r$ -quadrat, medium square root error (MSE), middle absolute error (MAE), and variance, square error (RMSE) in  $R$ -quadrat (RMSE). Of the five ML models, there is a random walk, five models with the highest accuracy and have a low error rate when predicting directories. In summary, we can say that the data and actual and expected results of machine learning from CST and ADS modeling indicate that the recommended antenna is a potential candidate for use in 5G.

### III. Meta Surfaces

In recent years, it has been examined that a large number of scientists showed huge interest in 2D planar metamaterials, namely metasurfaces. Metasurface exhibits similar phenomena as that of metamaterials and have very smaller thickness i.e. only a fraction of wavelength. Moreover, they are easier to fabricate and have negligible associated losses. A large range of optical devices have been implemented by employing metasurfaces, whereas the majority of them are based on abrupt phase changes for the manipulation of wavefront of light. Metasurfaces are basically planar metamaterials. Just like the metamaterials, the electric and magnetic polarizabilities are responsible for characterizing the response. These 2D equivalents are also called metafilms. Because of the customized values of permittivity and permeability, metamaterials can regulate the light propagation. This effect is still used in these materials to manipulate the electromagnetic waves. This, in turn, makes the overall structure bulkier, whereas the metasurfaces can manipulate these waves over a single and extremely thin layer. The 2D nature of metasurfaces offers a promising alternative, thereby making the structure less bulky, and providing the possibility of lower structural losses, easy fabrication, and integration [6]. They provide a variety of applications in the electromagnetic domain that range from low microwave to optical frequencies including controllable smart surfaces, terahertz switches,

miniaturized cavity resonators, angular independent surfaces, biomedical devices, and so on [7].

Due to their versatile nature, multifunctionality, ease of integration, and ultrathin features, these lately invented materials have recently attracted conspectus attention in comparison to their traditional counterparts [8]. Metasurfaces, the 2D version of metamaterials, are artificially engineered infinitely arranged ultrathin layer materials. They are made up of subwavelength meta-atoms called unit cells that are organized on a planar surface. The building blocks of metasurfaces consist of various material compositions that are arranged in various geometrical shapes to send the desired response to electromagnetic waves.

Owing to their subwavelength periodicity, these materials can be characterized by effective, uniform surface material parameters that include electric and magnetic sheet conductivities. They can also have various interesting properties and unique capabilities to control electromagnetic waves, according to the resonance properties and shape of meta-atoms [9].

### IV. Machine Learning

Machine Learning (ML) has become a transformative tool in antenna engineering, particularly for the design and optimization of MIMO (Multiple-Input Multiple-Output) antennas embedded with metasurfaces for 6G networks. Traditional antenna design methods rely heavily on time-consuming full-wave simulations and iterative adjustments. ML overcomes these limitations by enabling data-driven modeling and prediction, thereby reducing development time and enhancing performance accuracy.

#### Nearest Neighbors Algorithm

The Nearest Neighbor (NN) rule differentiates the classification of unknown data point because of closest neighbor whose class is known. The nearest neighbor is calculated based on estimation of  $k$  that represents how many nearest neighbors are taken to characterize the data point class. It utilizes more than one closest neighbor to find out the class where the given data point belong termed as KNN. The data samples are required in memory at run time called as memory-based technique. The training points are allocated weights based on their distances from the sample data point. However, the computational complexity and memory requirements remained key issue. For addressing the memory utilization problem, size of data gets minimized. The repeated

patterns without additional data are removed from the training data set [14].

### Naive Bayes Classifier

Naive Bayes Classifier technique is functioned based on Bayesian theorem. The designed technique is used when dimensionality of input is high. Bayesian Classifier is used for computing the possible output depending on the input. It is feasible to add new raw data at runtime. A Naive Bayes classifier represents presence (or absence) of a feature (attribute) of class that is unrelated to presence (or absence) of any other feature when class variable is known. Naïve Bayesian Classification Algorithm was introduced by Shinde S.B and Amrit Priyadarshi (2015) that denotes statistical method and supervised learning method for classification. Naive Bayesian Algorithm is used to predict the heart disease. Raw hospital dataset is employed. After that, the data gets preprocessed and transformed. Finally by using the designed data mining algorithm, heart disease was predicted and accuracy was computed.

### Support Vector Machine

SVM are used in many applications like medical, military for classification purpose. SVM are employed for classification, regression or ranking function. SVM depends on statistical learning theory and structural risk minimization principal. SVM determines the location of decision boundaries called hyper plane for optimal separation of classes as described in figure 3. Margin maximization through creating largest distance between separating hyper plane and instances on either side are employed to minimize upper bound on expected generalization error. Classification accuracy of SVM not depends on dimension of classified entities. The data analysis in SVM is based on convex quadratic programming. It is expensive as quadratic programming methods need large matrix operations and time consuming numerical computations.

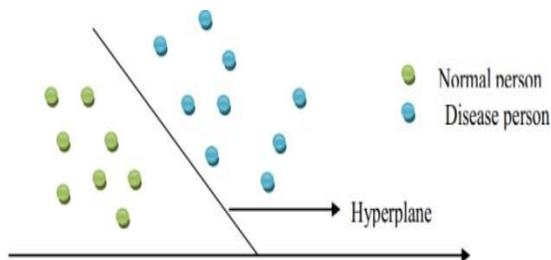


Fig. 1: Support Vector Classification

Applications of ML in this Context:

1. Performance Prediction: ML models (e.g., Support Vector Machines, Neural Networks) can accurately predict key antenna parameters such as return loss (S11), gain, bandwidth, and Envelope Correlation Coefficient (ECC) based on design inputs.

2. Optimization of Design Parameters: Algorithms such as Genetic Algorithms, Particle Swarm Optimization, and Reinforcement Learning can be applied to find the optimal geometry and configuration of metasurfaces for desired antenna behavior.

3. Pattern Recognition for Radiation Characteristics ML helps in classifying and analyzing radiation patterns to evaluate directionality and beam steering in complex metasurface environments.

4. Surrogate Modeling: Surrogate models trained with ML can replace complex simulations, enabling rapid prototyping and design exploration.

5. Adaptive Beamforming and Reconfiguration: ML enables smart beam control and adaptive reconfiguration of metasurface elements in real time to meet changing communication needs in a 6G environment.

### V. Why Use Metasurface Loaded MIMO Antennas?

The demand for faster, more reliable wireless communication in 6G networks requires advanced antenna solutions that offer high data rates, low latency, and efficient spectrum usage. Traditional antennas struggle to meet these challenges, especially at terahertz (THz) frequencies. This is where Metasurface-Loaded MIMO Antennas come into play.

#### Enhanced Beamforming and Directivity

Metasurfaces can dynamically control the phase and amplitude of electromagnetic waves, enabling precise beam steering and directional transmission, which are essential for high-frequency 6G systems.

Increased Channel Capacity (MIMO Benefits) MIMO systems allow multiple data streams to be transmitted simultaneously. When combined with metasurfaces, they reduce mutual coupling and improve isolation between antenna elements, boosting channel capacity and signal quality.

#### Compact and Lightweight Design

Metasurfaces help in miniaturizing antenna structures without compromising performance, making them ideal for portable and high-density IoT/6G devices.

#### Energy Efficiency

By focusing energy in desired directions and reducing signal losses, metasurface antennas contribute to lower power consumption and improved energy efficiency—a key goal in 6G.

#### Reconfigurability

Programmable or tunable metasurfaces allow real-time reconfiguration of antenna properties, enabling adaptability in dynamic environments and improving link reliability.

#### **Why Use Machine Learning for Metasurface Loaded MIMO Antennas?**

The design and optimization of metasurface-loaded MIMO antennas for 6G applications involve complex electromagnetic behaviors, numerous design parameters, and high computational costs. Machine Learning (ML) offers an intelligent and efficient solution to handle these challenges by enabling faster, more accurate, and adaptive antenna design processes.

#### Faster Design & Optimization

Designing metasurface antennas traditionally requires time-consuming full-wave electromagnetic simulations. ML models can learn from simulation data and predict antenna performance in milliseconds, reducing design cycles dramatically.

#### High-Dimensional Parameter Handling

Metasurfaces involve many variables—material properties, geometric shapes, periodicities, etc. ML algorithms excel at handling high-dimensional datasets and finding optimal combinations efficiently.

#### Performance Prediction

ML can predict key antenna characteristics (gain, S-parameters, bandwidth, ECC, etc.) based on input parameters, helping designers make informed decisions without the need for repetitive simulations.

### **VI. Conclusion**

This study presents an innovative approach to designing high-performance Metasurface-Loaded MIMO Antennas for future 6G wireless applications, integrated with Machine Learning algorithms for performance optimization. By incorporating

metasurfaces, the proposed antenna structure achieves improved characteristics such as enhanced gain, reduced mutual coupling, and better beamforming capabilities, all of which are critical for high-frequency 6G environments.

Machine Learning models significantly accelerate the design and optimization process by predicting key antenna parameters like gain, S-parameters, and ECC with high accuracy. This data-driven approach reduces dependency on repeated full-wave simulations, saving both time and computational resources.

The results demonstrate that ML-assisted metasurface MIMO antennas are not only efficient and compact but also adaptable to the demands of future terahertz communication systems. This fusion of intelligent design with advanced materials establishes a strong foundation for next-generation wireless infrastructure, paving the way for scalable, energy-efficient, and high-capacity 6G networks.

#### **References**

- [1] H. Li, Y. Zhang, and Z. N. Chen, "Machine Learning-Aided MIMO Antenna Design for 6G Communications," *IEEE Transactions on Antennas and Propagation*, vol. 72, no. 1, pp. 88–98, Jan. 2024.
- [2] A. Basu and R. Ghatak, "Reconfigurable Metasurface-Integrated MIMO Antenna for Terahertz 6G Applications," *IEEE Access*, vol. 12, pp. 45100–45110, 2024.
- [3] M. A. Habib, F. A. Tahir, and H. Tenhunen, "Deep Learning-Based Optimization of 6G THz MIMO Antennas," *IEEE Open Journal of Antennas and Propagation*, vol. 2, pp. 433–442, Dec. 2023.
- [4] N. Ahmed, S. Ullah, and H. Yoo, "Metamaterial and Metasurface-Enabled Antennas for 6G: A Review," *IEEE Access*, vol. 11, pp. 120340–120360, 2023, pp. 1870–1878, Feb. 2024.
- [5] Z. Zhao, L. Ge, and J. Li, "ML-Driven Performance Prediction of MIMO Antennas with Embedded Metasurfaces," *IEEE Sensors Journal*, vol. 24, no. 3, pp. 1870–1878, Feb. 2024.
- [6] P. Upender and A. Kumar (2021). Quad-Band Circularly Polarized Tunable Graphene Based Dielectric Resonator Antenna for Terahertz Applications, *Silicon*, vol. 14, pp. 5513-5526.

- [7] Kundan Kumar and Pradip Kumar Sadhu (2023). Performance prediction of a circularly polarized graphene-dielectric resonator-based antenna for THz frequency application using machine learning algorithms, *Applied Optics*, vol. 63, pp. 900-905.
- [8] P. Upender and A. Kumar (2023). THz Dielectric metamaterial sensor with high Q for biosensing applications, *IEEE Sens. J.*, vol. 23, pp. 5737-5744.
- [9] S. Zhang, Y. Pu, Z. Wu, and Y. Luo (2023). A New K-band 1-bit Broadband Reconfigurable Reflectarray Antenna, *Institute of Electrical and Electronics Engineers (IEEE)*, pp. 01–06.
- [10] M. Hakim, T. Alam, M. Islam, M. Baharuddin, and A. Alzamil (2022). Quad-Band Polarization-Insensitive Square Split-Ring Resonator (SSRR) with an Inner Jerusalem Cross Metamaterial Absorber for Ku- and K-Band Sensing Applications, *Sensors*, vol. 22, pp. 01-20.
- [11] B. Wang, C. Xu, and H. Zhou (2022). Realization of broadband terahertz metamaterial absorber using an antisymmetric resonator consisting of two mutually perpendicular metallic strips, *APL Materials*, vol. 10, pp. 01-08.
- [12] S. Banerjee, P. Dutta, A. Jha, P. Tripathi, A. Srinivasulu, B. Appasani, and C. Ravariu (2022). A Triple Band Highly Sensitive Refractive Index Sensor Using Terahertz Metamaterial Perfect Absorber, *Progress In Electromagnetics Research M*, vol. 107, pp. 13-23.
- [13] A. Kurshid, J. Dong, M. Ahmad, and R. Shi (2022). Optimized Super-Wideband MIMO antenna with high isolation for IoT applications, *Micromachines*, vol. 13, pp. 01-13.
- [14] W. Mu, H. Lin, Z. Wang, C. Li, M. Yang, W. Nie, and J. Wu (2022). A flower shaped miniaturized UWB-MIMO antenna with high isolation, *Electronics*, vol. 1, pp. 01-13.
- [15] S. Nithya, and V. Seethalakshmi (2022). MIMO antenna with isolation enrichment for 5G mobile information, *Hindawi Mobile Information Systems*, vol. 2022, pp. 01-14.
- [16] H. Kaur and H. Singh (2022). A High-Isolated CPW-Fed Multi-Band Metamaterial Inspired MIMO Antenna for Wireless Applications, in *Handbook of Metamaterial-Derived Frequency Selective Surfaces*, vol. 3, pp. 01-27.
- [17] P. Mallick, M. Ameen, R. Chowdhury, A. K. Ray, and R. K. Chaudhary (2022). Wideband Circularly Polarized Cavity-Backed Dielectric Resonator Antenna with Low RCS for Aerial Vehicle Communications, *IEEE Antennas Wirel. Propag. Lett.*, vol. 21, pp. 1418–1422.
- [18] Vishwanath, G. Varshney, and B. C. Sahana (2022). Implementing the single/multiport tunable terahertz circularly polarized dielectric resonator antenna, *Nano Commun. Netw.*, vol. 32, pp. 01-11.
- [19] P. Upender and A. Kumar (2022). HEM<sub>11δ</sub> and HEM<sub>12δ</sub>-based Quad band Quad Sense circularly polarized tunable Graphene-based MIMO Dielectric Resonator Antenna, *Frequenz*, vol. 76, pp. 273–285.

# **Color Image Compressor using Different types of Block Coding: A Study**

<sup>1</sup>Abhishek Nag, <sup>2</sup>Dr. Ram Milan Chadhar

<sup>1</sup>M. Tech. Scholar, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)

<sup>2</sup>Assistant Professor, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)

**Abstract-** Image compression plays a crucial role in reducing storage and transmission bandwidth while maintaining visual quality. In this study, we analyze the performance of different types of block coding techniques for color image compression. Block coding methods divide an image into fixed-size blocks and apply transformation, quantization, and entropy coding to achieve efficient data representation.

We evaluate various block-based compression techniques, including Vector Quantization (VQ), Block Truncation Coding (BTC), Discrete Cosine Transform (DCT)-based block coding, and Wavelet Block Coding (WBC). Each method offers unique advantages in terms of compression ratio, computational complexity, and image quality. Experimental results demonstrate a comparative analysis of these techniques based on metrics such as Peak Signal-to- Noise Ratio (PSNR), Structural Similarity Index (SSIM), and Compression Ratio (CR).

The findings of this study highlight the trade-offs between compression efficiency and visual fidelity, providing insights into the optimal selection of block coding techniques for color image compression applications, including multimedia storage, medical imaging, and remote sensing.

**Keywords—** Discrete Wavelet Transform, Multi-level, Block Truncation Code (BTC), PSNR MSE, Compression Ratio.

## **I. Introduction**

With the rise in multimedia technology and the growth of GUI-based software, digital image data

has become an inherent part of modern life. Scanning and quantizing 2D light intensity functions to create digital images can increase the amount of data generated, leading to enormous storage, processing and communication requirements. Therefore, data compression theory is becoming increasingly important to reduce data reductions in order to save more hardware and transmission bandwidth.

Data compression in computer science and information theory, data compression in coding information using fewer BITS, or other information storage units. Compression is useful because it contributes to reducing the consumption of expensive resources such as hard disk rooms and transmission bandwidth [1] [2]. BTC is a simple, quickly injured compression technique for grayscale images. The basic idea of BTC [3] is to perform instantaneous conservation of pixel block quantization. The entrance image is divided into non-duplicated blocks such as 4x4 and 8x8 pixel sizes. The block mean and standard deviation are calculated. The mean is determined as the threshold and reconstruction values using the mean and standard deviation.

Next, the bitmap of the block is derived based on the value of the threshold, which is a compressed or encoded image. The reconstructed image of the decoder is generated with reconstructed values and bitmap. Therefore, BTC generates the bitmap, the mean and standard deviation of each block in the coding process. When 4x4 blocks are considered, the compression ratio is 4 bits per pixel and bit rate. This method provides good compression without making the reconstructed image worse. However, it shows some artifacts, such as the effect of stairs and the rolling ones near the edges. Due to its simplicity and simple implementation, BTC has attracted great

interest in further development and application of image compression.

Several variations of BTC have been developed over the past few years to improve the quality of reconstructed images and improve compression efficiency. Absolute Moment Block Cutting Coding (AMBTC) [4] maintains a higher and lower average for each block and uses this amount to quantize the output. AMBTC offers better image quality than image compression using BTC. Furthermore, AMBTC is much faster than BTC. The algorithm is mathematically fast as it contains simple analytical formulas that calculate the parameters of edge functions in image blocks. The reconstructed images are of good quality according to human perception. This algorithm represents the image in terms of binary edge cards, medium information, and intensity information on both sides of the edge.

## II. Literature Survey

Shuyuan Zhu et al. [2018], transform domain downward conversion (TDDC) for image coding is usually implemented by discarding some high frequency components from each transformed block. As a result, a block of fewer coefficients is formed and a lower compression cost is achieved due to the coding of only a few low-frequency coefficients. In this paper, we focus on the design of a new TDDC-based coding method by using our proposed interpolation-compression directed filtering (ICDF) and error-compensated scalar quantization (ECSQ), leading to the compression-dependent TDDC (CDTDDC) based coding. More specifically, ICDF is first used to convert each  $16 \times 16$  macroblock into an  $8_8$  coefficient block. Then, this coefficient block is compressed with ECSQ, resulting in a smaller compression

distortion for those pixels that locate at some specific positions of a macro-block. We select these positions according to the 4:1 uniform sub-sampling lattice and use the pixels locating at them to reconstruct the whole macro-block through an interpolation.

The proposed CDTDDC-based coding can be applied to compress both grayscale and color images. More importantly, when it is used in the color image compression, it offers not only a new solution to reduce the data-size of chrominance components but also a higher compression efficiency. Experimental results demonstrate that applying our proposed CDTDDC-based coding to compress still images can achieve a significant quality gain over the existing compression methods.

Shih-Lun Chen et al. [2017], color and multispectral image compression using Enhance block truncation code is proposed [1]. These techniques are based on standard deviation and mean. This technique is applied to satellite image and reshapes the satellite image. The satellite image is divided into various sub-blocks. After calculate mean values, all number of pixel in sub-block are compared to the mean and according to the mean all pixel value is replaced by binary number. Finally MSE, PSNR and compression ratio are calculated for the Enhance block truncation code for satellite image.

Sunwoong Kim et al. [2016], with the continuing growth of modern communication technologies, demand for image data compression is increasing rapidly. Techniques for achieving data compression can be divided into two basic approaches: spatial coding and Transform coding. This research paper presents a proposed method for the compression of digital images using hybrid compression method based on Block Truncation Coding (BTC) and Walsh Hadamard Transform (WHT). The objective of this hybrid approach is to achieve higher compression ratio by applying BTC and WHT. Several grayscale test images are used to evaluate the coding efficiency and performance of the hybrid method and compared with the BTC and WHT respectively. It is generally shown that the proposed method gives better results. Processing dependency in the conventional algorithm is removed by partitioning the input image and modifying neighboring reference pixel configuration. Experimental results show that the parallel implementation drastically reduce processing time by 6~7 times with significant visual quality improvement.

C. Senthil kumar et al. [2016], In this paper, image compression plays vital role in saving memory storage space and saving time while transmission images over network. The color and multispectral image is considered as input image for the image compression. The proposed technique with Enhanced Block Truncation Coding [EBTC] is applied on component of color and multispectral image. The component image is divided into various sub blocks. After evaluating mean values, the number of bits can be reduced by Enhanced Block Truncation Coding. Finally, compression ratio table is generated using the parameters such as MSE, SNR and PSNR. The proposed method is implemented through standard color and multispectral images using MATLAB Version 8.1 R2013a.

Jing-Ming Guo et al. [2014], Block truncation committal to writing (BTC) has been thought of

extremely economical compression technique for many years. Moreover, this method can provide excellent processing efficiency by exploiting the nature parallelism advantage of the dot diffusion, and excellent image quality can also be offered through co-optimizing the class matrix and diffused matrix of the dot diffusion. According to the experimental results, the proposed DDBTC is superior to the former error-diffused BTC in terms of various objective image quality assessment methods as well as processing efficiency.

A modified Block Truncation Coding using max-min quantizer (MBTC) is proposed in this paper to overcome the above mentioned drawbacks. In the conventional BTC, quantization is done based on the mean and standard deviation of the pixel values in each block. In the proposed method, instead of using the mean and standard deviation, an average value of the maximum, minimum and mean of the blocks of pixels is taken as the threshold for quantization.

Jayamol Mathews et al. [2013], with the emerging multimedia technology, image data has been generated at high volume. It is thus important to reduce the image file sizes for storage and effective communication. Block Truncation Coding (BTC) is a lossy image compression technique which uses moment preserving quantization method for compressing digital gray level images. Even though this method retains the visual quality of the reconstructed image with good compression ratio, it shows some artifacts like staircase effect, raggedness, etc. near the edges. A set of advanced BTC variants reported in literature were studied and it was found that though the compression efficiency is good, the quality of the image has to be improved. A modified Block Truncation Coding using max-min quantizer (MBTC) is proposed in this paper to overcome the above mentioned drawbacks. In the conventional BTC, quantization is done based on the mean and standard deviation of the pixel values in each block. In the proposed method, instead of using the mean and standard deviation, an average value of the maximum, minimum and mean of the blocks of pixels is taken as the threshold for quantization. Experimental analysis shows an improvement in the visual quality of the reconstructed image by reducing the mean square error between the original and the reconstructed image. Since this method involves less number of simple computations, the time taken by this algorithm is also very less when compared with BTC.

### III. Previous Design

Coupling ICDF and ECSQ together, we build up the compression-dependent TDDC (CDTDDC) for the compression of image signals and the framework of this coding scheme is shown in Fig. 1. Moreover, when the proposed CDTDDC based coding is adopted in the compression of grayscale images, it will work competitively with the JPEG baseline coding as two coding modes for each macro-block. On the other hand, when it is used to compress color images, it is only performed on two chrominance components after the RGB to- YCbCr conversion. In this way, it offers not only a new solution to reduce the data-size of color images but also a high compression efficiency.

### IV. Methodology

#### •Discrete Wavelet Transform

Wavelets are signals which are local in time and scale and generally have an irregular shape. A wavelet is a waveform of effectively limited duration that has an average value of zero. The term „wavelet“ comes from the fact that they integrate to zero; they wave up and down across the axis. Many wavelets also display a property ideal for compact signal representation: orthogonality. This property ensures that data is not over represented. A signal can be decomposed into many shifted and scaled representations of the original mother wavelet. A wavelet transform can be used to decompose a signal into component wavelets. Once this is done the coefficients of the wavelets can be decimated to remove some of the details. Wavelets have The compression features of a given wavelet basis are primarily linked to the relative scarceness of the wavelet domain representation for the signal. The notion behind compression is based on the concept that the regular signal component can be accurately approximated using the following elements: a small number of approximation coefficients (at a suitably chosen level) and some of the detail coefficients.

The steps of compression algorithm based on DWT

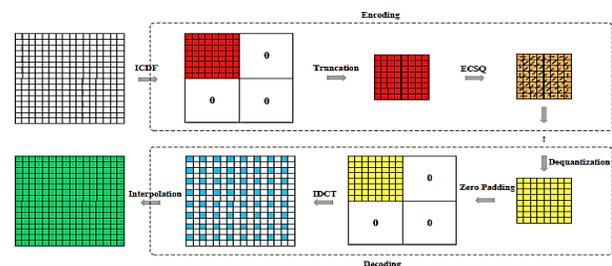


Fig. 1 Architecture

are described below:

I. Decompose Choose a wavelet; choose a level N. Compute the wavelet. Decompose the signals at level N.

II. Threshold detail coefficients For each level from 1 to N, a threshold is selected and hard thresholding is applied to the detail coefficients.

III. Reconstruct Compute wavelet reconstruction using the original approximation coefficients of level N and the modified detail coefficients of levels from 1 to N.

•Multi-level Block Truncation Code

The Encoder and decoder block of the multi-level block truncation code algorithm is shown if figure 2. Encoder part of the proposed algorithm shows that the original image is divided into three parts i.e. R component, G component and B component. Each R, G, B component of the image is divided into non overlapping block of equal size and threshold value for each block size is being calculated.

Threshold value means the average of the maximum value (max) of „k × k“ pixels block, minimum value (min) of „k × k“ pixels block and m1 is the mean value of „k × k“ pixels block. Where k represents block size of the color image. So threshold value is: the great advantage of being able to separate the fine details in a signal. Very small wavelets can be used to isolate very fine details in a signal, while very large wavelets can

$$T = \frac{\max + \min + m_1}{3}$$

identify coarse details. In addition, there are many different wavelets to choose from. Various types of wavelets are: Morlet, Daubechies, etc. [6]. This technique first decomposes an image into coefficients called sub-bands and then the resulting coefficients are compared with a threshold. Coefficients below the threshold are set to zero. Finally, the coefficients above the threshold value are encoded with a loss less compression technique.

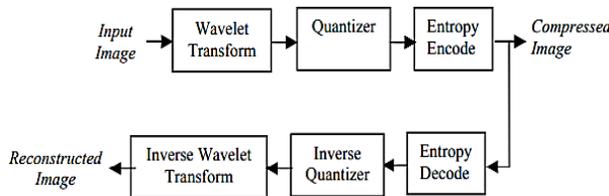


Fig. 2: The structure of the wavelet transform based compression

Each threshold value is passing through the quantization block.

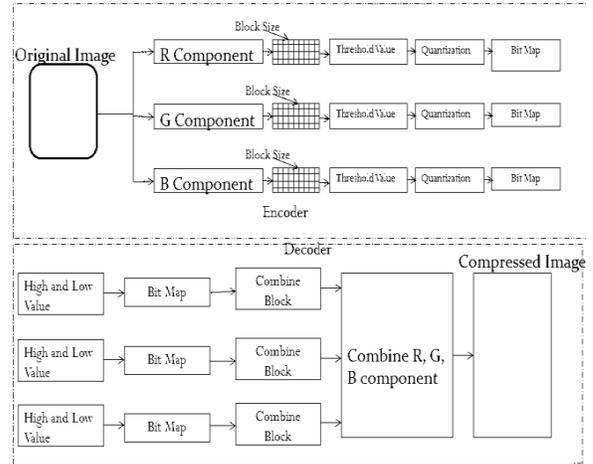


Fig. 3: Block Diagram of Proposed Algorithm

Quantization is the process of mapping a set of input fractional values to a whole number. Suppose the fractional value is less than 0.5, then the quantization is replaced by previous whole number and if the fractional value is greater than 0.5, then the quantization is replaced by next whole number.

Each quantization value is passing through the bit map block. Bit map means each block is represented by „0“ and

„1“ bit map. If the Threshold value is less than or equal to the input image value then the pixel value of the image is represent by „0“ and if the threshold value is greater than the input image value then the pixel value of the image is represented by „1“.

Bit map is directly connected to the high and low component of the proposed decoder multi-level BTC algorithm. High (H) and low (L) component is directly connected to the bit map, bitmap converted the „1“ and „0“ pixel value to high and low pixel value and arrange the entire block.

$$L = \frac{1}{q} \sum_{i=1}^p w_i w_i \leq T$$

$$H = \frac{1}{q} \sum_{i=1}^p w_i w_i > T$$

Wi represent the input color image block, q is the number of zeros in the bit plane, p is the number of

ones in the bit plane. In the combine block of decoder, the values obtained from the pattern fitting block of individual R, G,B components are combined after that all the individual combined block are merged into a single block . Finally compressed image and all the parameter relative to that image will be obtained.

•Error-compensated scalar quantization

The application of ICDF in the TDDC-based coding aims at a better interpolation and a lower compression cost. However, when the compression happens, the interpolation efficiency as well as the coding efficiency will be limited by the distortion occurring on those filtered pixels (denoted as  $\sim x$ ) that will be used for interpolation. To solve this problem, we purpose to reduce the sum of square error (SSE) distortion of  $\sim x$  as much as possible via controlling the quantization error of the transformed macro-block based on an error-compensated scalar quantization (ECSQ).

**V. Proposed Methodology**

Transmission and storage of raw images require huge quantity of disk space. Hence, there is an urgent need to reduce the size of image before sending or storing. The best possible solution to the problem is to use compression methods where the compression of data on digital images are made to reduce irrelevance and redundancy of the image data to be able to efficiently store or transmit data. Most of the existing compression techniques employed have their negatives and an enhanced technique which is faster, effective and memory efficient can definitely satisfy the requirements of the user.

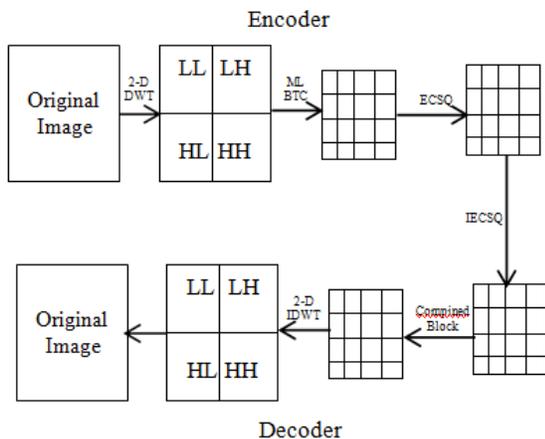


Fig. 4: Proposed Methodology

Image compression thrives to store or transmit the data in a proficient mode as well as to offer a best image quality at a specified bit-rate. Image compression can be done in lossy or lossless mode. Lossless compression is preferred for objectives and mainly used in medical imaging technical drawings, clip art, or comics. This is due to the introduction of compression artifacts, low bit rates and also because the resources cannot be considerably saved by using image compression method. Lossy methods are especially suitable for natural images such as photographs in applications where negligible loss of fidelity is tolerable to attain a considerable reduction in bit rate. Here conciliated ensuing image quality devoid of much perception by the viewer is achieved.

**VI. Conclusion**

In this study, we analyzed and compared different block coding techniques for color image compression, including Vector Quantization (VQ), Block Truncation Coding (BTC), Discrete Cosine Transform (DCT)-based block coding, and Wavelet Block Coding (WBC). Each method demonstrated distinct advantages in terms of compression ratio, computational complexity, and image quality.

Experimental results showed that DCT-based block coding provides an excellent balance between compression efficiency and perceptual quality, making it ideal for applications such as JPEG compression. Wavelet-based block coding (WBC) outperformed other methods in preserving fine details, making it suitable for high-quality medical and satellite imaging. On the other hand, Vector Quantization (VQ) and BTC offered faster compression and reduced computational complexity, making them ideal for real-time applications where processing speed is a priority.

Overall, the choice of block coding technique depends on the specific application requirements, such as storage efficiency, computational constraints, and desired image quality. Future work can focus on hybrid approaches that combine multiple block coding techniques for further optimization in compression performance.

**References**

[1]Poonlap Lamsrichan, “Straightforward Color Image Compression Using True-Mean Multi- Level Block Truncation Coding”, IEEE International Conference on Consumer Electronics (ICCE), IEEE 2021.

- [2] Haichuan Ma Dong Liu Ning Yan Houqiang Li and Feng Wu. End-to-end optimized versatile image compression with wavelet-like transform. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 2020.
- [3] Fabian Mentzer George Toderici Michael Tschannen and Eirikur Agustsson. High-fidelity generative image compression. *arXiv preprint arXiv:2006.09965* 2020.
- [4] H. H. Cheng C. A. Chen L. J. Lee T. L. Lin Y. S. Chiou and S. L. Chen "A low-complexity color image compression algorithm based on AMBTC" 2019 IEEE International Conference on Consumer Electronics- Taiwan (ICCE-TW) May 2019.
- [5] C. A. Chen S. L. Chen C. H. Lioa and P. A. R. Abu "Lossless CFA image compression chip design for wireless capsule endoscopy" *IEEE Access* vol. 7 pp. 107047-107057 Jul. 2019.
- [6] Emiel Hoogeboom Jorn WT Peters Rianne Van Den Berg and Max Welling. Integer discrete flows and lossless compression. *arXiv preprint arXiv:1905.07376* 2019. 1.
- [7] Shuyuan Zhu, Zhiying He, Xiandong Meng, Jiantao Zhou and Bing Zeng, "Compression-dependent Transform Domain Downward Conversion for Block- based Image Coding", *IEEE Transactions on Image Processing*, Volume: 27, Issue: 6, June 2018.
- [8] Shih-Lun Chen and Guei-Shian Wu, "A Cost and Power Efficient Image Compressor VLSI Design with Fuzzy Decision and Block Partition for Wireless Sensor Networks", *IEEE Sensors Journal*, Volume: 17, Issue: 15, Aug.1, 1 2017.
- [9] Sunwoong Kim and Hyuk-Jae Lee, "RGBW Image Compression by Low-Complexity Adaptive Multi- Level Block Truncation Coding", *IEEE Transactions on Consumer Electronics*, Vol. 62, No. 4, November 2016.
- [10] C. Senthil kumar, "Color and Multispectral Image Compression using Enhanced Block Truncation Coding [E-BTC] Scheme", accepted to be presented at the IEEE WiSPNET, PP. 01-06, 2016 IEEE.
- [11] Jing-Ming Guo, Senior Member, IEEE, and Yun-Fu Liu, Member, IEEE, "Improved Block Truncation Coding Using Optimized Dot Diffusion", *IEEE Transactions on Image Processing*, Vol. 23, No. 3, March 2014.
- [12] Jayamol Mathews, Madhu S. Nair, "Modified BTC Algorithm for Gray Scale Images using max-min Quantizer", 978-1-4673-5090-7/13/\$31.00 ©2013 IEEE.
- [13] M. Brunig and W. Niehsen. Fast full search block matching. *IEEE Transactions on Circuits and Systems for Video Technology*, 11:241 – 247, 2001.
- [14] K. W. Chan and K. L. Chan. Optimisation of multi- level block truncation coding. *Signal Processing: Image Communication*, 16:445 – 459, 2001.
- [15] Ki-Won Oh and Kang-Sun Choi, "Parallel Implementation of Hybrid Vector Quantizerbased Block Truncation Coding for Mobile Display Stream Compression", *IEEE ISCE 2014* 1569954165.
- [16] Seddeq E. Ghrare and Ahmed R. Khobaiz, "Digital Image Compression using Block Truncation Coding and Walsh Hadamard Transform Hybrid Technique", 2014 IEEE 2014 International Conference on Computer, Communication, and Control Technology (I4CT 2014), September 2 - 4, 2014 - Langkawi, Kedah, Malaysia.
- [17] C. C. Chang and T. S. Chen. New tree-structured vector quantization with closed-coupled multipath searching method. *Optical Engineering*, 36:1713 – 1720, 1997.
- [18] C. C. Chang, H. C. Hsia, and T. S. Chen. A progressive image transmission scheme based on block truncation coding. In *LNCS Vol 2105*, pages 383–397, 2001.

# **A Smart Platform for Real-Time Cattle Health Surveillance**

<sup>1</sup>Atul Gorakhnath Karle <sup>2</sup>Dr. Rajesh Kumar Rai, <sup>3</sup>Dr. Rammilan Chadhar

<sup>1</sup>Research Scholar, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)

<sup>2</sup>Professor, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)

<sup>3</sup>Assistant Professor, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)

**Abstract:** The paper focuses on developing a robust and intelligent cattle health monitoring system that leverages cutting-edge technologies to track vital health indicators and deliver real-time insights to livestock producers. Consistent monitoring is essential for extending the lifespan of cattle and maintaining the quality of dairy production. However, on large-scale farms, it is often difficult for workers to continuously monitor the health of individual animals due to time and labor limitations. This system is designed to enhance the efficiency and sustainability of livestock operations. By utilizing advanced technologies such as skin temperature sensors, heart rate monitors, and motion detectors it enables continuous monitoring of critical health metrics including heart rate, activity levels, heat stress, and sleep patterns. All collected data is centralized on a web-based platform, where machine learning algorithms process and analyze the information to assess the health status of each animal.

A companion mobile application provides intuitive visualizations and instant alerts, allowing farm operators to take timely action when health issues arise. This forward-thinking solution aims to transform cattle health management by enabling early disease detection, improving resource efficiency, and ultimately increasing the profitability of livestock production. Traditional health monitoring in the cattle industry often depends on manual observation and data entry, which can be inefficient, prone to error, and too slow to catch emerging health problems. This system offers a proactive alternative designed to detect potential health concerns before they escalate, helping to reduce disease-related losses and improve overall herd well-being.

**Keywords:** Machine Learning (ML), Cattle health monitoring, IoT(Internet of Things), Disease Prevention.

## **I. Introduction**

The cattle industry plays a crucial role in the global food supply, with over 1.4 billion cattle raised worldwide. However, it faces significant challenges such as disease outbreaks, declining productivity, and inefficiencies in health monitoring. Traditionally, cattle health has been monitored through manual inspections—a process that is time-consuming, labor-intensive, and often ineffective for early disease detection.

These methods typically rely on visual assessments, which can be subjective and prone to error, allowing illnesses to spread rapidly and jeopardize the entire industry.

To address these issues, the Department is encouraging the adoption of precision animal husbandry. A key innovation in this area is the Agrisense Integrated Health Surveillance for Cattle system. This advanced solution uses wireless sensor networks, the Internet of Things (IoT), and artificial intelligence to continuously monitor cattle health, behavior, and environmental conditions. By providing real-time data, Agrisense enables early detection of health issues, supports timely interventions, and enhances overall animal welfare.

Maintaining the health of dairy cattle is essential for maximizing both productivity and profitability in agriculture. Factors such as proper nutrition, housing, vaccination, parasite control, and reproductive management are vital for optimal performance. Through consistent monitoring of

these areas, farmers can prevent disease, boost reproductive success, and improve milk yields.

Technological innovations like Agrisense represent a significant step forward in livestock management. IoT devices continuously collect and analyze data on vital signs, behavioral patterns, and environmental metrics. This empowers farmers with actionable insights, reduces economic losses, and supports a proactive approach to animal health management.

## **II. Literature Review**

Design of Smart Domestic Farming Based on the Internet of Things (IoT)" by Mayur Pillewan, Dr. Rahul Agrawal, and Dr. Nikhil Wyawahare explores recent advancements in the use of IoT for monitoring and managing animal environments. The review emphasizes how IoT technology can be used to track environmental parameters like temperature and humidity within domestic farms and pet houses, while also controlling water supply systems. A key feature of the system includes monitoring for dangerous animals through photography and alerting farmers via alarms when such threats are detected. Insecticides are also integrated to target pests like mosquitoes, flies, and ticks, and the system can help identify the presence of wild animals such as tigers, lions, wolves, and leopards. Additionally, temperature regulation for animals is managed using fans and heaters, and proximity or infrared sensors are used to track the number of animals entering and exiting enclosures, sending this data directly to the farmer.

Internet of Things (IoT) and Machine Learning (ML) Enabled Livestock Monitoring" by Abdul Aziz Chaudhry, Rafia Mumtaz, and Syed Mohammad Hassan Zaidi, the authors review and compare existing livestock monitoring solutions and technologies. They propose a rapid monitoring system based on IoT, incorporating a custom-designed multi-sensor card to capture vital physical parameters such as body temperature, heart rate, and environmental sensitivity. The system also utilizes image analysis to recognize behavioral patterns. Data collected by the sensors is transmitted via WiFi or GSM to a central server, where machine learning algorithms analyze the information to detect signs of disease and assess overall cattle health. This enables early intervention and timely treatment, ultimately improving livestock management and animal welfare

## **III. Methodology**

A. Data collection: Surveillance can be divided into two main types: passive and active. These approaches utilize various methods, such as direct and indirect visual monitoring. Data is collected from a wide range of sources, including farmers, veterinarians, lab test results, and other stakeholders. This multi-source strategy provides a well-rounded view, ensuring a robust and comprehensive monitoring system that supports timely responses to emerging health issues.

B. Data Analysis: Before analysis, the collected data must be cleaned and processed to ensure it is accurate, complete, and ready for use. Once prepared, descriptive statistics like averages, medians, and standard deviations are used to summarize the data. Next, inferential statistical methods are applied to uncover trends, patterns, and correlations that can guide decision-making and strategic planning.

C. Risk Assessment: This stage begins with identifying hazards that could negatively impact cattle health. After recognizing potential threats, a risk evaluation is conducted to estimate both the likelihood and severity of each risk. Based on these risk scores, hazards are prioritized, allowing for focused management of the most critical threats to animal health.

D. Decision-Making: Establishing threshold values is essential for detecting diseases and determining when an outbreak should be declared. To support sound decision-making, decision trees can be developed to outline appropriate responses in various scenarios. Involving key stakeholders in this process is important, as their insights contribute to more informed and effective outcomes.

E. Response and Control: In the event of an outbreak or emergency, rapid activation of response protocols is crucial. Control measures should be swiftly implemented to contain the disease. Following this, ongoing monitoring and evaluation of these interventions ensure that the response is effective and adjustments can be made as needed.

F. Communication and Feedback: Efficient communication with all stakeholders including farmers and veterinary staff is vital for coordinated action. Establishing feedback channels allows stakeholders to provide input and share experiences. Documenting lessons learned and best practices helps enhance future surveillance and response efforts by leveraging past insights.

G. Continuous Improvement: Ongoing evaluation of the surveillance system is necessary to identify potential improvements. Quality assurance processes should also be in place to maintain the accuracy and reliability of the collected data, ensuring the overall integrity of the surveillance system over time

#### IV. Block Diagram

A. Cattle (Cow): The primary subject being monitored is the cow, which wears a collar or belt equipped with various health-monitoring sensors.

B. Sensor Node: Sensors attached to the cow collect vital data such as body temperature, heart rate, and movement. This data provides a detailed view of the animal's overall health and wellbeing.

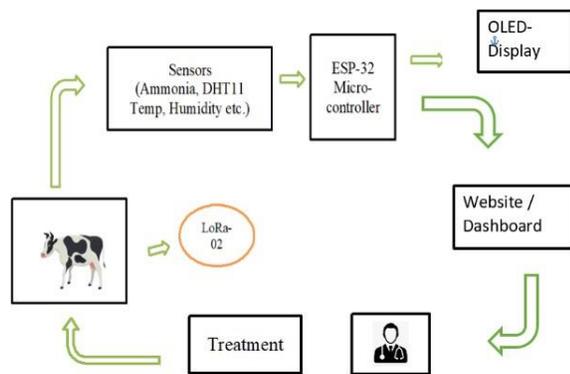


Fig.1 Block diagram of system

C. ESP-32 Microcontroller: The system uses an ESP32 microcontroller, which is a cost-effective, energy-efficient device featuring built-in Wi-Fi and Bluetooth connectivity.

D. LoRa Communication Module (LoRa-02): This module transmits data wirelessly over long

distances, making it suitable for rural farm areas where traditional network coverage may be unreliable.

E. OLED Display: Real-time data, such as temperature, humidity, or gas levels, is displayed locally on an OLED screen for quick visual checks by farmers.

F. Online Dashboard: The collected data is also sent to a web-based dashboard, allowing remote monitoring by farmers or veterinarians. The dashboard includes visual insights like alerts, trends, and predictive analytics.

G. Treatment and Alerts: If any health parameter exceeds normal thresholds (e.g., high temperature or ammonia levels), alerts are automatically generated. These alerts prompt caretakers to take action, such as informing a veterinarian or administering first-aid or preventive treatment based on the symptoms. The IoT-based cattle health monitoring system uses various biomedical sensors like temperature, humidity, and ammonia sensors embedded in a collar. These sensors continuously monitor the cow's health metrics and convert them into electrical signals. These signals are then evaluated against predefined normal ranges. If anomalies are detected, the system alerts the farmer, who can then consult a veterinarian. If no vet is immediately available, the farmer can transmit the animal's health data remotely. The veterinarian can review health trends and graphs to provide advice or recommend treatment even in emergency cases.

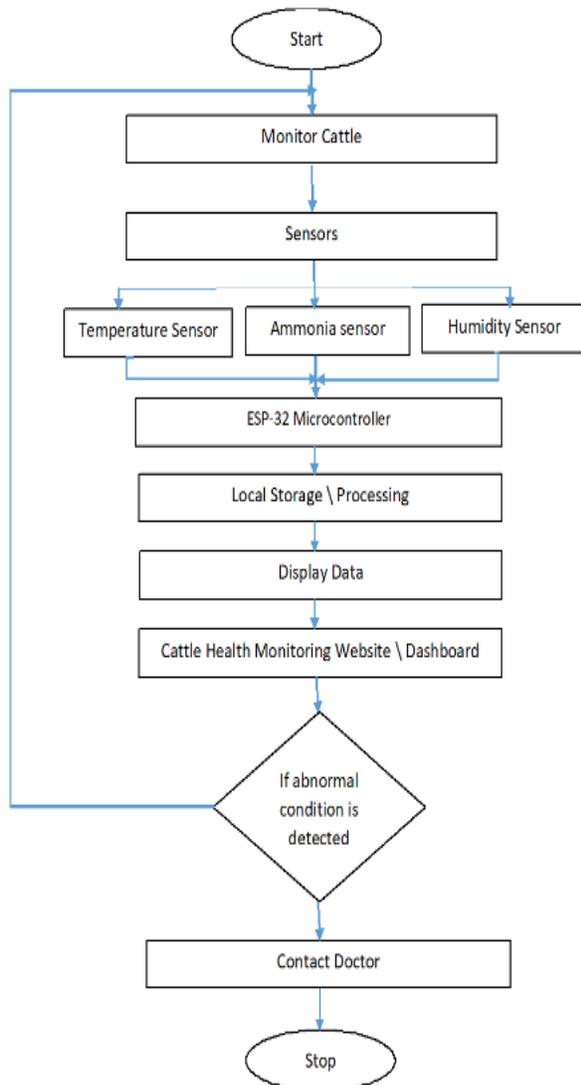


Fig. 2 Flowchart for system

## References

- [1] M. Pillewan, R. Agrawal, N. Wyawahare and L. Thakare, "Review on Design of Smart Domestic Farming based On Internet of Things (IOT)", 2023 Third International Conference on Artificial Intelligence and Smart Energy (ICAIS), pp. 36-40, February 2023.
- [2] P. Yadav, S. Chandra, P. Kumar and P. Kumar, "Digital Farming: IoT Enabled Smart Sensor Based Insect and Animal Detection System", Int. J. of Aquatic Science, vol. 12, no. 2, pp. 2564-2573, 2021.
- [3] Chaudhry, Abdul Aziz, Rafia Mumtaz, Syed Mohammad Hassan Zaidi, and Muhammad Ali Tahir, et al. "Internet of Things (IOT) and Machine Learning (ML) enabled livestock monitoring." In 2020.

## VI. Conclusion

This study offers a detailed examination of a cattle health monitoring system that plays a crucial role in advancing modern livestock management. It supports early detection of health issues, boosts productivity, and promotes sustainable farming by enabling data-driven decisions and improving reproductive efficiency. These monitoring systems are a vital resource for today's agricultural practices. By leveraging technology and real-time data, they help ensure the health and welfare of animals while contributing to efficient and environmentally responsible livestock production.

# **Remote Sensing and GIS-Based Flood Inundation Mapping: The Wainganga River Basin, Maharashtra**

<sup>1</sup>Anand T. Deshkar, <sup>2</sup>Dr. Vivek Soni, <sup>3</sup>Dr. Sapna Madan,

<sup>1</sup>Research Scholar, Madhyanchal Professional University.

<sup>2</sup>Guide, Madhyanchal Professional University.

<sup>3</sup>Co-Guide, Madhyanchal Professional University.

**Abstract:** The Wainganga River Basin in Maharashtra, a region of significant agricultural and ecological importance, frequently experiences severe monsoon flooding, causing substantial socio-economic disruptions. Addressing the critical need for proactive flood management, this research employs integrated remote sensing (RS) and Geographic Information System (GIS) techniques to map flood hazard zones and delineate vulnerable areas. The primary objective is to provide a comprehensive understanding of flood dynamics and inundation patterns, focusing on the past three decades. The methodology integrates multi-temporal satellite imagery from Landsat and Sentinel missions with Digital Elevation Models (DEMs) for terrain analysis. Additionally, gridded rainfall data is analysed to inform the demarcation of flood lines. GIS platforms are utilized for data processing, spatial analysis, and the generation of detailed flood inundation maps. This research further examines the historical impacts of floods on agriculture and population within the basin. The findings are intended to significantly enhance flood preparedness, inform mitigation strategies, and support sustainable water resource management. By identifying high-risk areas, this research provides valuable data for disaster management authorities, strategic river planning, and community resilience efforts in the Wainganga River Basin.

**Keywords:** GIS, Remote Sensing (RS), Wainganga river basin, Grid rainfall, Flood impact map.

## **1. Introduction**

Riverine flooding, characterized by the inundation of land adjacent to river channels when discharge exceeds bankfull capacity, constitutes a significant natural hazard in India, frequently inflicting substantial damage upon human lives, property, critical infrastructure, and agricultural yields. While primarily driven by high discharge volumes, flood events can also be triggered or exacerbated by factors such as temporary channel obstructions caused by landslides, failures of water management structures like dams, or breaches in embankments. Indian rivers, particularly during the monsoon season, often transport considerable sediment loads originating from their

catchments. The resultant siltation can lead to inadequate channel conveyance capacity, which is a primary factor contributing to increased flood propensity, widespread drainage congestion in low-lying areas, and dynamic fluvial processes including bank erosion and deposition.

Effective flood management necessitates accurate spatial delineation of vulnerable areas. Consequently, the development of flood hazard or impact maps for specific regions, such as the study area herein, is crucial for informing scientifically sound river management strategies and guiding sustainable developmental planning to mitigate flood risk. The hydrological regime of many Indian river basins is dominated by the Southwest Monsoon, typically concentrating around eighty per cent of the annual precipitation between June and September. This intense seasonal rainfall pattern significantly influences the flood dynamics of basins like the Wainganga sub-basin, the focus of this study. Historical data indicates that the Wainganga sub-basin is inherently susceptible to flooding, with significant events recorded at intervals of approximately 5-7 years. Notably, the basin has witnessed substantial floods in recent times, including the years 2001, 2004, 2007, and 2013, 2017, 2019, 2023 underscoring the recurrent nature of this hazard.

## **2. Research Area**

The Wainganga River originates at an elevation of 640.0 meters in the Seoni District of Madhya Pradesh, specifically from the western slopes of the Maikala Ranges, which constitute an extension of the Satpura Ranges in Central India. The river receives numerous tributaries along its course, effectively draining the western, central, and eastern regions of the Chandrapur, Gadchiroli, Bhandara, Gondia, and Nagpur districts within Maharashtra. Geographically, the river basin extends approximately from 19°30'N to 22°30'N latitude and 79°00'E to 80°30'E longitude.

The Wainganga River receives significant contributions from several key tributaries:

- **Kanhan River:** The largest tributary, originating in Madhya Pradesh and joining the Wainganga near Ambora village in Nagpur district, Maharashtra. (average annual discharge of 450–600 m<sup>3</sup>/s)

## International Conference on Advances in Science and Engineering (ICASE2025)

- **Bawanthadi River:** This river forms a segment of the border between Maharashtra and Madhya Pradesh and confluences with the Wainganga near Mowad in Nagpur district, in proximity to the Bhandara-Nagpur region. (average annual discharge of 150–200 m<sup>3</sup>/s)
- **Kathani River:** This river flows entirely within Maharashtra and contributes to the Wainganga from the east, joining near Desaiganj (Wadsa) in Gadchiroli district. (average annual discharge of 50–70 m<sup>3</sup>/s)
- **Sur River:** A relatively smaller river that confluences near Brahmपुरi in Chandrapur district, playing a notable role in local agricultural water supply. (average annual discharge of 75–85 m<sup>3</sup>/s) These tributaries collectively contribute significantly to the Wainganga's flow, particularly during the monsoon season, supporting agricultural activities and water supply infrastructure in the Vidarbha region of Maharashtra.

The Wainganga River confluences with the Wardha River at Gundapet; the Wardha flows from the west and drains a significant portion of the Maharashtra Plateau. Following this confluence, the combined flow is subsequently designated as the Pranhita River. The Pranhita River joins the Godavari River on its left bank, which drains the Eastern Coast in Andhra Pradesh before discharging into the Bay of Bengal. The average annual discharge of the Wainganga River, measured at downstream stations such as Ashti, is approximately 572.146 m<sup>3</sup>/s.

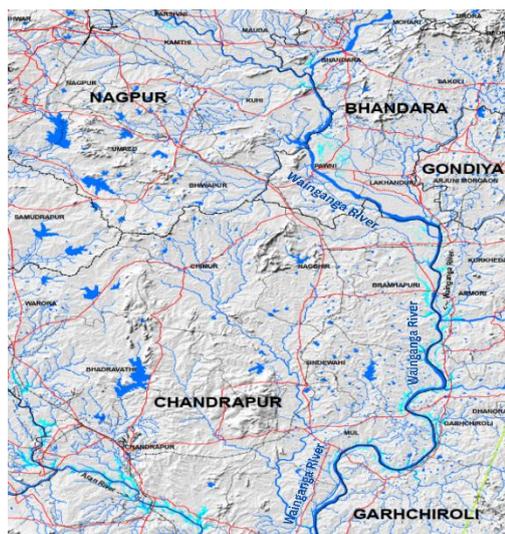


Figure 1. Wainganga River flowing through Bhandara, Gondia, Chandrapur and Gadchiroli Districts

### 3. Methodology

For the present flood analysis studies, spatial data were primarily acquired from one-inch topographic maps published by the Survey of India, utilizing scales of either 1: 63,360 or 1: 250,000. Specific toposheet numbers employed included 55K, 55O, 55P, 56M, 64C, 64D, and 65A. The methodological approach encompassed several stages: data organization, digitization of various thematic

layers, map generation, and statistical analysis. Geospatial techniques, including geo referencing, data integration, and area calculation, were applied. Map products were generated utilizing ArcGIS and ERDAS Imagine software platforms. Furthermore, rainfall distribution data were obtained from the Indian Meteorological Department (IMD) 0.25°×0.25° grid dataset to prepare the rainfall distribution map. Thematic maps depicting rainfall distribution, slope, micro watershed size, drainage density, soil type, and land use/land cover for each micro watershed were systematically prepared using ArcGIS software. Weights were assigned to each class within these thematic layers. Finally, an integrated Flood Impact map was produced by combining these weighted thematic layers.

### 4. Literature Review

Research on flood inundation and hazard assessment within the Wainganga River Basin increasingly leverages remote sensing (RS), Geographic Information Systems (GIS), and hydrological/hydraulic modeling. Several studies demonstrate the utility of RS and GIS for identifying and mapping flood-prone areas, often integrating factors like grid rainfall data to generate flood impact maps aimed at improving river management and development planning (Bhagat & Bisen, 2016). Complementary GIS-based approaches utilize multi-criteria analysis, incorporating parameters such as rainfall distribution, to delineate flood hazard zones and support sustainable planning initiatives within the Maharashtra portion of the basin (Bhagat et al., 2021). Furthermore, the analysis of watershed characteristics using RS and DEM data provides crucial insights into the basin's physiographic conditions and their influence on hydrological responses and flood patterns (Bisen, 2021). Hydraulic modeling, particularly using HEC-RAS integrated with GIS, has been effectively applied to analyze specific flood scenarios, simulating inundation extent and water levels for various return periods along critical river reaches near urban centers like Bhandara and Balaghat (Ingale & Shetkar, 2017; Bhawsar et al., 2022). Addressing the challenge of data scarcity, continuous simulation hydrological models like PDM, driven by gridded climate data, have been employed to estimate annual maximum flows and generate flood frequency curves, thereby aiding in the prediction of extreme flood events even in sparsely gauged areas of the Wainganga basin (Vesuviano et al., 2022). Collectively, these studies highlight a multi-faceted approach, combining geospatial analysis with advanced modeling techniques, to enhance the understanding and management of flood risk in the Wainganga River Basin.

### 5. Results and Discussions

#### 5.1. Land Use/ Land Cover

Land Use/Land Cover (LULC) characteristics significantly influence the hydrological response of a catchment and are considered a critical factor in modulating flood hazards. An

International Conference on Advances in Science and Engineering (ICASE2025)

analysis of the Wainganga River basin identified several distinct LULC classes, including rocky/open areas, dense forest, water bodies, agricultural land, sparse vegetation, fallow land, open scrub, barren land, settlements, and gravel land. Forest cover constitutes the predominant LULC type, encompassing 65.75% of the basin. This category includes dense deciduous forests (15.03%), primarily located in the eastern parts of the basin, along with sparse vegetation (23.01%), open scrub (27.71%), degraded forests, forest blanks, and recent plantations. Agricultural land, representing 14.17% of the area and typically featuring kharif, rabi, and double cropping systems, plays a role in attenuating runoff due to vegetation cover, which intercepts precipitation and slows surface flow. Conversely, categories associated with increased runoff generation include barren land (9.48%), characterized by soils unsuitable for plant growth, and fallow land (4.19%), which can impede the free flow of runoff. Other identified classes include built-up or settlement areas (1.89%), water bodies (2.11%), rocky/open land (1.88%), and gravel land (0.52%). Wasteland and barren rocky/stony areas are also present. The LULC classification for this analysis was derived using a supervised classification methodology within ERDAS Imagine software, with subsequent spatial analysis performed using ArcGIS tools.

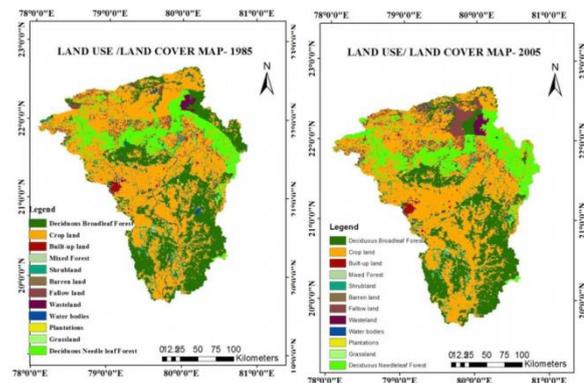


Figure 2: Land Use Land Cover Map of Wainganga Basin (LULC)

5.2. Soil Type

Soil type represents a critical determinant in flood hazard zonation, primarily because the soil's infiltration capacity governs the partitioning of precipitation between subsurface flow and surface runoff. Lower infiltration rates directly contribute to increased surface runoff, thereby elevating flood susceptibility. The Wainganga River basin exhibits a diversity of soil types, which not only influence hydrological processes but also dictate agricultural suitability and practices within the region. Information regarding the spatial distribution and characteristics of these soils was sourced from Survey of India topographic maps and data provided by the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP). Analysis indicates that a specific soil subtype, designated as subtype 45, is the predominant soil classification across the

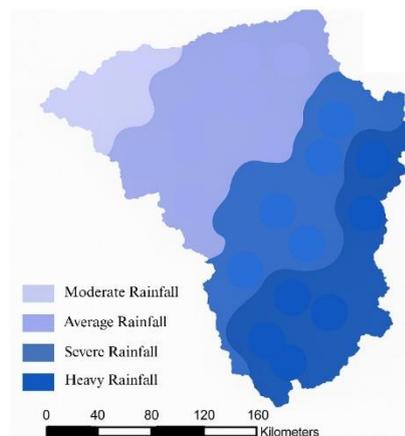
majority of the study area within the Wainganga sub-basin. Understanding the properties of dominant soil types, particularly their infiltration characteristics, is essential for accurately assessing flood risk.

5.3 Morphometry control on flood

The Wainganga basin, a 7th-order drainage system according to Strahler's stream ordering method, encompasses a total of 4870 streams. This includes 3318 first-order, 1117 second-order, 331 third-order, 88 fourth-order, 11 fifth-order, and 4 sixth-order streams. The basin exhibits a mean bifurcation ratio of 3.55, suggesting a natural river network characterized by uniformity in climate, lithology, and developmental stage. The number of stream segments in the Wainganga basin is approximately 2786.1, following the typical pattern of decreasing stream count with increasing order. Portions of the Wainganga River with a sinuosity index exceeding 1.41 are classified as meandering. The dominant drainage pattern observed in the Wainganga sub-basins is dendritic to dendritic. The basin has a coarse drainage density of 0.70 km/km<sup>2</sup>, and a low stream frequency of 0.18 per km<sup>2</sup>. This low stream frequency indicates a basin likely characterized by dense vegetation cover and permeable subsoil.

5.4 Rainfall distribution

Rainfall data from the India Meteorological Department (IMD) for 49 grid stations were utilized to generate spatial



Average Rainfall in Wainganga Basin since 2000 to 2024

Figure 3: Average Annual Rainfall in Wainganga Basin Since 2000 to 2024

and temporal rainfall maps for the Wainganga River basin in Maharashtra. This analysis, conducted on gridded rainfall data at a 0.25°×0.25° resolution spanning the period from 1961 to 2014, aimed to understand rainfall distribution, a critical factor in flood hazard zonation, as high-intensity rainfall events are often precursors to significant flooding

## **International Conference on Advances in Science and Engineering (ICASE2025)**

when water volume surpasses the carrying capacity of stream and river channels. Trend analysis revealed statistically significant decreasing trends in annual rainfall for the years 1972, 1974, 1984, 1987, 1991, 1996, and 2004 within the study period. Overall, a notable decrease in annual rainfall was observed in 1972. Conversely, the year 1992 exhibited the most pronounced change towards higher rainfall in both annual and monsoonal totals. Increasing rainfall trends were identified for the years 1961, 1975, 1978, 1990, 1992, 1994, 2001, 2005, 2007, 2013, 2017, 2019, and 2023 within the analyzed timeframe.

### **5.5 Impact of Flood Line on Wainganga River**

To evaluate the spatial extent of flooding, Geographic Information System (GIS) methodologies were applied across the Bhandara, Nagpur, Gondia, Chandrapur, and Gadchiroli districts. Flood impact maps were developed based on the analysis of historical precipitation records, classifying areas into two risk categories based on rainfall thresholds of >1000mm and >500mm. The zone identified as high-risk primarily includes regions bordering the entire length of the Wainganga River. Establishing precise flood lines is essential for informed land-use decisions and effective disaster preparedness in both rural and urban settings.

An examination of flood occurrences between 1961 and 2024 indicated substantial inundation in Gondia district, affecting 201 villages and an area of 336.35 km<sup>2</sup>. In Bhandara district 64 vilages were affected. During the same flood events, Chandrapur district experienced impacts in 112 villages. In Gadchiroli district, 122 villages were flooded, with a total affected area of 254.11 km<sup>2</sup>. Within Nagpur district and the vicinity of the Wainganga River, approximately 322.13 km<sup>2</sup> were impacted by flooding, and around 98 villages were found to be repeatedly susceptible. The resulting flood impact maps offer valuable information regarding the maximum extent of inundation in flood-prone areas, contributing to a better understanding of the river's dynamic behavior within the study area.

### **6. Conclusion**

This research aimed to delineate flood lines and assess the spatial impact of risk zones within the Wainganga River basin through the integration of Survey of India toposheets, Cartosat Digital Elevation Model (DEM), and satellite imagery. Geographic Information System (GIS) technology proved instrumental in identifying areas with heightened flood vulnerability. The findings of this study hold practical significance for communities residing in flood-prone villages within the basin.

The analysis concluded that the primary driver of flash flood events in the Wainganga basin is the rapid accumulation of substantial water volumes, often in conjunction with sudden and intense rainfall episodes. Consequently, the identified potential flood risk areas necessitate careful consideration in the formulation of

comprehensive disaster preparedness and pre-warning systems.

In the Indian context, where monsoon-driven rainfall patterns are often characterized by high variability and intensity, the accurate demarcation of flood lines and identification of vulnerable zones are crucial for mitigating the socio-economic impacts of flooding. The insights generated from this study can empower both individuals and local authorities to implement appropriate proactive and reactive measures. For instance, pre-warning notices disseminated based on these risk assessments can facilitate timely evacuations and the safeguarding of assets. Furthermore, this spatial understanding of flood vulnerability can inform more resilient land-use planning and infrastructure development in the region, aligning with national disaster risk reduction frameworks. The integration of such spatial analysis into local governance structures can lead to more informed decision-making and ultimately contribute to building safer and more resilient communities within the Wainganga River basin and similar flood-prone regions across India.

### **7. References**

1. Bhagat, R. S., & Bisen, D. K. (2016). Flood Study of Wainganga River in Maharashtra Using GIS & Remote Sensing Techniques. *International Journal of Science and Research (IJSR)*, 5(4), 782-785. DOI: 10.21275/NOV162684.
2. Ingale, H., & Shetkar, R. V. (2017). Flood analysis of Wainganga River by using HEC-RAS Model. *International Journal of Scientific Engineering and Technology*, 6(4), 211-215.
3. Bhagat R.S., Kudnar N.S. and Shinde H.D. (2021). GIS-Based Multi-criteria Approach towards Sustainability of Rainfall distribution and Flood hazard Areas in Wainganga River in Maharashtra, India. *Maharashtra Bhugolshastra Sanshodhan Patrika*, 38(2), 39-46.
4. Bhawsar, P., Babu, A. K., & Garg, C. (2022). Flood Analysis of Wainganga River in Lower Godavari Basin Using HECRAS. *Journal of Water Resources and Pollution Studies*, 7(3).
5. Vesuviano, G., Griffin, A., & Stewart, E. (2022). Flood Frequency Estimation in Data-Sparse Wainganga Basin, India, Using Continuous Simulation. *Water*, 14(18), 2887. DOI: 10.3390/w14182887.
6. Bisen, D. K. (2021). Remote Sensing and GIS Based Comparative study of watershed of different Physiographic Conditions, Wainganga Sub Basin, Maharashtra. *International Journal of Research and Analytical Reviews (IJRAR)*, 8(2), 25-33.

# **Congestion Avoidance in Wireless Communication Network using Machine Learning Technique**

<sup>1</sup>Bhupendra Kumar, <sup>2</sup>Dr. Reeta Pawar, <sup>3</sup>Dr. Ram Milan Chadhar

Ph.D. Scholar, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)<sup>1</sup>

Professor, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)<sup>2</sup>

Assistant Professor, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)<sup>3</sup>

**Abstract:** Wireless communication networks are increasingly prone to congestion due to the rapid growth of connected devices and high data traffic demand. Traditional congestion control mechanisms struggle to adapt dynamically to network variations, leading to performance degradation. This study explores the application of machine learning techniques to predict and mitigate congestion in wireless networks efficiently. By analyzing real-time network parameters such as traffic load, latency, and packet loss, a predictive model is developed to anticipate congestion and take proactive measures. Various machine learning approaches, including Support Vector Machines (SVM), Deep Learning, and Reinforcement Learning, are evaluated for their effectiveness in congestion avoidance. Experimental results demonstrate that the proposed model significantly improves network performance by reducing packet loss, optimizing bandwidth utilization, and minimizing transmission delays. This research highlights the potential of intelligent congestion avoidance strategies to enhance the reliability and efficiency of wireless communication networks.

**Keywords:** Wireless Communication, Machine Learning, Congestion Avoidance.

## **I. Introduction**

These are small, inefficient areas where you can control the performance is slow; it is very difficult to grab or charge it. As a result, most sensor nodes are lost and the lifestyle of sensor nodes in wireless networks is very low. WSN rely solely on energy consumption. It is designed to use minimal energy as a result of amount of energy spent on communication would be greater if communicated to another knot rather than. Analyzed and proven. Due to the overwhelming exchange of information on that has been made at any time, it is impossible for to prevent overload. Various studies have been proposed to prevent traffic congestion in wireless networks. However, the general idea is that WSN can be controlled by existing sensor nodes that control data

traffic with traditional transport protocol (TTP) [1, 2].

TCP has been proposed as a transport layer protocol recorded a defect in traditional traffic for the as follows: If a sensor node in a WSN sends information to a remote sensor node, the information is probably and overloads the information before it arrives [3, 4]. It is very difficult to implement an overload control method to avoid the wireless networks are very difficult to provide a guarantee so that information is achieved from one sensor to the other sensor nodes.

- Like TCP, events must be run that operate on wireless sensor networks. The does not require end-to-end guaranteed transfers.
- Sensor nodes in the sensor network are informationplans and should be minimal overhead.
- TCP requires three ways to achieve a message toand make sure the message reaches the information until it receivesand guarantee.
- The congestion control system will be used for a longer period of time. Thisuses wireless channels over time. Verification of informationtakes time to provide, and then a long-term RTT is used.
- Wireless sensor networks need protocols that can control more traffic. The sensor node is designed to have a lifetime energy at the, which has very low energy consumption.

One type of network that uses lightweight data transport is a sensor network. Sensor nodes can occasionally become suddenly active and inactive [5, 6]. The more sensors there are in the sensor network, it generates more traffic. Consequently, the information supplied more network traffic is generated at the sensor node than is utilized because it exceeds the volume of traffic. In addition, abruptly or irrevocably the node of departure of the sensor becomes congested. The most crucial element is the management of congestion in the wireless sensor network. At the same time, the conglomerates enable the integration of channels or the expansion of data that it transmits. As a result, numerous protocols are discovered to be avoided

International Conference on Advances in Science and Engineering (ICASE2025)

them. It becomes more difficult with some of these methods. Any traffic jams the control system works well for as much information as possible, and this approach ought to be taken. Various types of solutions for controlling congestion should be taken into account for this. In recent years, a number of methods have been discussed [7]. In any case, it is a respectable method of congestion control. This implies that the data is transmitted to the sensor node or via other sensor nodes that facilitate communication

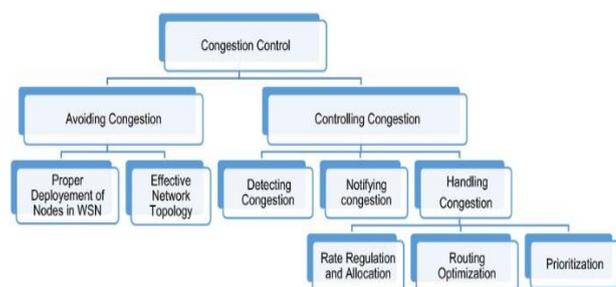


Fig. 1: Congestion Control in WSN

II. Sources and Causes of Congestion

We currently discuss the congestion regulatory made through the source sensor node

(i) Buffer Occupancy: The source sensor node should know the type of information that a sensor node will include and the output information. On that basis the sensor should send its information. If the rate of information is increased when sent, then the sensor node should sense that this is caused by buffer occupancy.

(ii) Channel Contention: While it uses its channel at a sensor node, the same channel is used by different sensor nodes on the network. The sensor nodes are sent on a variety of information on that channel. When sending it, the information sent from one node is at the top of that bandwidth is created on the channel. To find this, the channel is detecting congestion.

(iii) Interference: The sensor among the sensor nodes closest to the sensor is that it is caused by different sensors sent their data over the same channel.

(iv) Packet Collisions: When more than one sensor node is trying to send its message to a channel, its information is likely to be collided.

(v) Many-to-One Traffic: When information comes from a wide range of sensors, it causes radio frequency overlap.

(vi) Concurrent Transmission: The simultaneous use of multiple station sensors causes its information to be transmitted to its full capacity.

(vii) Reporting Rate: A sensor node must be sent data to the amount assigned to it. Whether is increased or not, it can lead to a congestion.

(viii) Addition or Removal of Sensor Nodes: The sensor

nodes in a sensor network leads to strangulation by connecting with new ones or by removing a node from it.

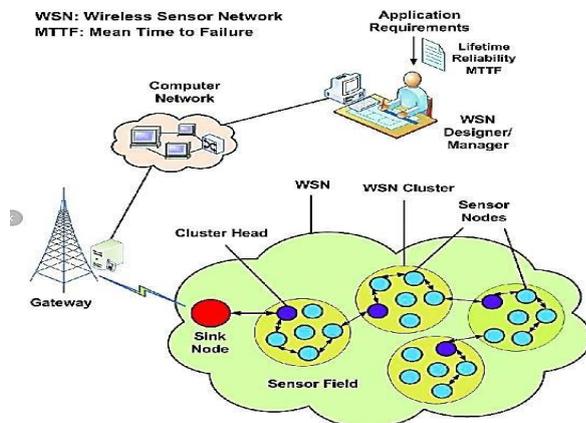


Fig. 2: WSN Architecture

III. Machine Learning

Uproarious information is available in the heap of substance that will be identified through the anomaly strategies. The information can be spatial or can be a transient method spatial connected with the geological conditions and worldly connected with the time perspectives [14, 15]. The principle point of exception identification is to deal with the loud information that is introduced in the heap of text. Different methods for recognizing abnormalities in Text are specified in below:

Learning

The main property of an ML is its capability to learn. Learning or preparing is a procedure by methods for which a neural system adjusts to a boost by making legitimate parameter modifications, bringing about the generation of wanted reaction. Learning in an ML is chiefly ordered into two classes as [16].

- Supervised learning
- Unsupervised learning

Supervised Learning

Regulated learning is two stage forms, in the initial step: a model is fabricated depicting a foreordained arrangement of information classes or ideas. The model developed by investigating database tuples portrayed by traits. Each tuple is expected to have a place with a predefined class, as dictated by one of the qualities, called to have a place with a reclassified class, as controlled by one of the traits called the class name characteristic. The information tuple are dissected to fabricate the model all things considered from the preparation dataset [17].

Unsupervised learning

It is the kind of learning in which the class mark of each

## International Conference on Advances in Science and Engineering (ICASE2025)

preparation test isn't known, and the number or set of classes to be classified may not be known ahead of time. The prerequisite for having a named reaction variable in preparing information from the administered learning system may not be fulfilled in a few circumstances.

Data mining field is a highly efficient techniques like association rule learning. Data mining performs the interesting machine-learning algorithms like inductive-rule learning with the construction of decision trees to development of large databases process. Data mining techniques are employed in large interesting organizations and data investigations. Many data mining approaches use classification related methods for identification of useful information from continuous data streams.

### Nearest Neighbors Algorithm

The Nearest Neighbor (NN) rule differentiates the classification of unknown data point because of closest neighbor whose class is known. The nearest neighbor is calculated based on estimation of  $k$  that represents how many nearest neighbors are taken to characterize the data point class. It utilizes more than one closest neighbor to find out the class where the given data point belong termed as KNN. The data samples are required in memory at run time called as memory-based technique. The training points are allocated weights based on their distances from the sample data point. However, the computational complexity and memory requirements remained key issue. For addressing the memory utilization problem, size of data gets minimized. The repeated patterns without additional data are removed from the training data set [18].

### Naive Bayes Classifier

Naive Bayes Classifier technique is functioned based on Bayesian theorem. The designed technique is used when dimensionality of input is high. Bayesian Classifier is used for computing the possible output depending on the input. It is feasible to add new raw data at runtime. A Naive Bayes classifier represents presence (or absence) of a feature (attribute) of class that is unrelated to presence (or absence) of any other feature when class variable is known. Naïve Bayesian Classification Algorithm was introduced by Shinde S.B and AmritPriyadarshi (2015) that denotes statistical method and supervised learning method for classification. Naive Bayesian Algorithm is used to predict the heart disease. Raw hospital dataset is employed. After that, the data gets preprocessed and transformed. Finally by using the designed data mining algorithm, heart disease was predicted and accuracy was computed.

### Support Vector Machine

SVM are used in many applications like medical, military for classification purpose. SVM are employed for classification, regression or ranking function. SVM depends on statistical learning theory and structural risk

minimization principal. SVM determines the location of decision boundaries called hyper plane for optimal separation of classes as described in figure 3. Margin maximization through creating largest distance between separating hyper plane and instances on either side are employed to minimize upper bound on expected generalization error. Classification accuracy of SVM not depends on dimension of classified entities. The data analysis in SVM is based on convex quadratic programming. It is expensive as quadratic programming methods need large matrix operations and time consuming numerical computations.

Figure 3: Support Vector Classification

## IV. Methodology

Identify the specific congestion issues in wireless networks (e.g., packet loss, high latency, low throughput).

Define key performance metrics: Packet Delivery Ratio (PDR), Throughput, Latency, and Packet Loss Ratio. Select the type of network: 4G, 5G, IoT, MANETs, VANETs, etc.

### Data Collection

Simulation Data: Use network simulators like NS-3, OMNeT++, or MATLAB to generate congestion scenarios.

Real-World Data: Collect network traffic logs from datasets such as CRAWDDAD or network monitoring tools (Wireshark, NetFlow).

Feature Engineering: Extract relevant features like network load, bandwidth, delay, jitter, and queue size.

### Data Preprocessing

Handling Missing Data: Fill missing values using interpolation or statistical methods.

Normalization: Scale numerical values for better model convergence.

Feature Selection: Use Principal Component Analysis (PCA) or Mutual Information to reduce dimensionality.

Data Splitting: Divide data into training, validation, and test sets.

### Model Selection

Choose a machine learning technique based on the network environment:

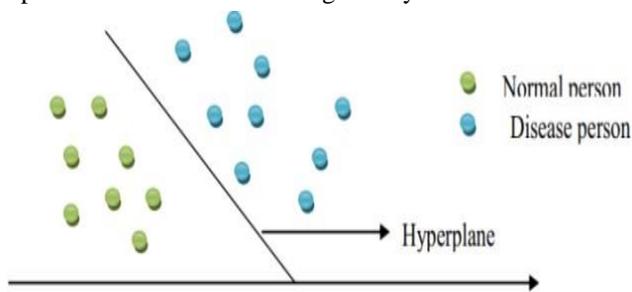
#### Supervised Learning:

Support Vector Machines (SVM), Decision Trees, Random Forest for classification (congested vs. non- congested).

Regression models (Linear Regression, XGBoost) to predict congestion levels.

#### Unsupervised Learning:

K-Means or DBSCAN for anomaly detection in network traffic.



## **International Conference on Advances in Science and Engineering (ICASE2025)**

### **Reinforcement Learning (RL):**

Q-Learning, Deep Q-Networks (DQN), or Actor-Critic models to dynamically manage congestion.

Works well for adaptive congestion control based on traffic patterns.

### **Model Training and Evaluation**

Training: Train the ML model on historical network traffic data.

### **Evaluation Metrics:**

Classification Models: Accuracy, Precision, Recall, F1-score.

Regression Models: Mean Squared Error (MSE), Root Mean Squared Error (RMSE).

RL Models: Reward function optimization for dynamic congestion control.

### **Deployment and Real-Time Monitoring**

Implement the trained model into a real-time network monitoring system.

Use cloud-based deployment with APIs (e.g., TensorFlow Serving, Flask, FastAPI).

Integrate with Software-Defined Networking (SDN) controllers for dynamic routing and congestion management.

- Performance Optimization and Fine-Tuning
- Use hyperparameter tuning (Grid Search, Bayesian Optimization).
- Test the model under different network conditions and traffic loads.
- Implement feedback loops to improve model accuracy over time.

## **V. Conclusion**

In this study, we explored the application of machine learning techniques for congestion avoidance in wireless communication networks. Traditional congestion control mechanisms often fail to adapt to dynamic network conditions, leading to performance issues such as increased latency, packet loss, and reduced throughput. To address these challenges, we developed and evaluated machine learning-based predictive models capable of detecting and mitigating congestion in real time.

Our results demonstrate that machine learning approaches, such as Support Vector Machines (SVM), Deep Learning, and Reinforcement Learning, can effectively anticipate congestion and optimize network performance. By analyzing key network parameters, our model enables proactive congestion management, leading to improved bandwidth utilization, reduced transmission delays, and enhanced overall network efficiency.

The findings of this research highlight the potential of intelligent congestion avoidance techniques in modern wireless networks. Future work may focus on refining the model with more advanced deep learning architectures, integrating it with emerging technologies like 5G and IoT, and evaluating its performance under diverse network scenarios. The adoption of machine learning in congestion control paves the way for more adaptive and resilient wireless communication systems.

### **References**

- [1] X. Nie et al., "Dynamic TCP initial windows and congestion control schemes through reinforcement learning", *IEEE J. Sel. Areas Commun.*, vol. 37, no. 6, pp. 1231-1247, Jun. 2019.
- [2] J. C. Hoe, "Improving the start-up behavior of a congestion control scheme for TCP", *ACM SIGCOMM Comput. Commun. Rev.*, vol. 26, no. 4, pp. 270-280, 1996.
- [3] Y. Zaki, T. Pötsch, J. Chen, L. Subramanian and C. Görg, "Adaptive congestion control for unpredictable cellular networks", *Proc. 2015 ACM Conf. Special Interest Group Data Commun.*, pp. 509-522, 2015.
- [4] K. Winstein and H. Balakrishnan, "TCP ex machina: Computer-generated congestion control", *ACM SIGCOMM Comput. Commun. Rev.*, vol. 43, no. 4, pp. 123-134, 2013.
- [5] W. Li, H. Zhang, S. Gao, C. Xue, X. Wang and S. Lu, "SmartCC: A reinforcement learning approach for multipath TCP congestion control in heterogeneous networks", *IEEE J. Sel. Areas Commun.*, vol. 37, no. 11, pp. 2621-2633, Nov. 2019.
- [6] R. Xie, X. Jia and K. Wu, "Adaptive online decision method for initial congestion window in 5G mobile edge computing using deep reinforcement learning", *IEEE J. Sel. Areas Commun.*, vol. 38, no. 2, pp. 389-403, Feb. 2020.
- [7] N. Jay, N. Rotman, B. Godfrey, M. Schapira and A. Tamar, "A deep reinforcement learning perspective on internet congestion control", *Proc. Int. Conf. Mach. Learn.*, pp. 3050-3059, 2019.
- [8] L. Zhang, K. Zhu, J. Pan, H. Shi, Y. Jiang and Y. Cui, "Reinforcement learning based congestion control in a real environment", *Proc. 29th Int. Conf. Comput. Commun. Netw. (ICCCN)*, pp. 1-9, 2020.
- [9] R. Kohavi et al., "Scaling up the accuracy of Naive-Bayes classifiers: A decision-tree hybrid", *Proc. KDD*, vol. 96, pp. 202-207, 1996.
- [10] I. Ahmad, S. Shahabuddin, H. Malik, E. Harjula, T. Leppänen, L. Loven, A. Anttonen, A.H. Sodhro, M.M. Alam, M. Juntti, et al., "Machine learning meets communication networks: Current trends and future challenges", *IEEE Access* 8 (2020) 223418– 223460.
- [11] L. Lemus Cárdenas, A.M. Mezher, J.P. Astudillo

**International Conference on Advances in Science and Engineering (ICASE2025)**

León, M. Aguilar Igartua, DTMR: A decision tree- based multimetric routing protocol for vehicular ad hoc networks, in: Proceedings of the 18th ACM Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, & Ubiquitous Networks, 2021, pp. 57–64.

[12] L. Lemus Cárdenas, A.M. Mezher, P.A. Barbecho Bautista, J.P. Astudillo León, M.A. Igartua, A multimetric predictive ANN-based routing protocol for vehicular ad hoc networks, *IEEE Access* 9 (2021) 86037–86053.

[13] L.L. Cárdenas, J.P. Astudillo León, A.M. Mezher, GraTree: A gradient boosting decision tree based multimetric routing protocol for vehicular ad hoc networks, *Ad Hoc Netw.* 137 (2022) 102995.

[14] C.L. Duenas Santos, J.P. Astudillo León, A.M. Mezher, J. Cardenas Barrera, J. Meng, E. Castillo Guerra, RPL+: An improved parent selection strategy for RPL in wireless smart grid networks, in: Proceedings of the 19th ACM International Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, & Ubiquitous Networks, 2022, pp. 75–82.

[15] Jagannathan, S.; Almeroth, K.C. Using tree topology for multicast congestion control. In Proceedings of the International Conference on Parallel Processing, Valencia, Spain, 3–7 September 2001; p. 313.

[16] Katuwal, R.; Suganthan, P.; Zhang, L. An ensemble of decision trees with random vector functional link networks for multi-class classification. *Appl. Soft Comput.* 2018, 70, 1146–1153.

# **COVID-19 effect on healthcare management workers in India and Madhya Pradesh**

**Garima Pandey**

<sup>1</sup>PhD Scholar, [garimap207@gmail.com](mailto:garimap207@gmail.com), Department of Management, Madhyanchal Professional University, Bhopal-462044, M.P., India

**Abstract:** The COVID-19 (corona virus disease of 2019) pandemic has profoundly impacted healthcare systems globally, with healthcare management workers (HCMWs) bearing the brunt of its challenges. In India, particularly in Madhya Pradesh, the crisis exposed significant systemic vulnerabilities while highlighting the resilience and dedication of healthcare personnel. This study examines the multifaceted effects of the pandemic on HCMWs in India, with a focused lens on Madhya Pradesh. It explores operational, psychological, and infrastructural dimensions, analyzing how the surge in cases overwhelmed existing healthcare facilities, led to resource scarcity and placed immense physical and emotional stress on workers. Healthcare administrators faced unprecedented pressure to manage logistics, maintain staffing levels, and ensure the safety of frontline workers while adapting to rapidly changing protocols and government mandates. In Madhya Pradesh, where public health infrastructure is relatively underdeveloped, these challenges were intensified by rural-urban disparities, limited ICU and oxygen support, and inconsistent supply chains. The study also highlights the adaptive strategies implemented, including digital health solutions, staff cross-training, and policy reforms aimed at bolstering emergency preparedness. Despite systemic challenges, the crisis catalyzed long-term healthcare reforms, including enhanced data management, increased adoption of telemedicine, and expanded mental health support for workers. The findings underscore the need for a robust, well-supported healthcare management workforce and call for continuous investment in training, infrastructure, and crisis preparedness to mitigate future public health emergencies. This research contributes to

understanding how healthcare systems can evolve through crisis and underscores the human cost of pandemic mismanagement.

**Keywords:** COVID-19, Healthcare workers, HCMWs, Madhya Pradesh, Healthcare Infrastructure.

## **I. Introduction:**

The COVID-19 outbreak caused by the SARS-CoV-2 virus in 2019 rapidly intensified into a global health emergency, placing immense pressure on healthcare systems worldwide. (Vizheh, Qorbani, & Esmaeili, 2020) In India, the global pandemic tested the clinical capacity of hospitals, medical staff, and frontline workers, highlighting

the crucial role of healthcare management workers (HCMWs). These HCMWs include administrators, coordinators, and support personnel who ensure the smooth functioning of medical facilities across hospitals, nursing homes, and primary health centres, as well as National Health Mission (NHM) staff. These individuals were instrumental in handling the operational aspects of the crisis (Sharma & Tiwari, 2022), from managing patient inflow and resource allocation to coordinating staff rotations and implementing evolving health protocols (Chemali, Mari-Saez, & Heide, 2022)

Issues in different HCMWs were reported globally during the COVID-19 pandemic. For example, burnout in 220 medical staff working in oncology medicine in Wuhan, China, was measured (Nishtha, Dhamija, Patil, & Chaudhari, 2021) using the Maslach Burnout Inventory-Medical Personnel. Burnout in the frontline was compared to that of another group of HCWs. Surprisingly, the frontline HCMWs had significantly lower levels of burnout and were way less worried about becoming infected when compared to the ones in the usual wards. Two possible explanations were deduced; the first was that the frontline HCWs perceived more control over the situation, and the second was that they appeared closer to decision-making than the other HCMWs. Similarly, changes in sleep patterns and sleep deprivation were observed in HCMWs. For example, under conditions of psychological distress, sleep is usually disturbed. A survey was conducted among 180 medical staff members to assess the impact of COVID-19 on social support, anxiety, stress, self-efficacy, and sleep quality. It was found that social support correlated significantly with self-efficacy and sleep quality. Anxiety and stress were significantly increased, leading to negative impacts on both self-efficacy and sleep (Nishtha, Dhamija, Patil, & Chaudhari, 2021). Stress is an essential factor in drug use.

Researchers have shown that major stressors increase the risk of developing an addiction, as well as the risk of relapse. Stress, fear, and anxiety have increased, too, for people on the frontlines as they face the gravest danger (Nishtha, Dhamija, Patil, & Chaudhari, 2021). It was reported in March 2020 that, among doctors in China, up to 40% had mild-to-moderate depressive symptoms. However, another survey on a small number of HCMWs in China found that the workers showed signs of psychological distress during the pandemic. The data are sparse regarding

## **International Conference on Advances in Science and Engineering (ICASE2025)**

the impact of the pandemic on the health of doctors in developing countries. Moreover, a recent survey conducted in 2016 among doctors working in a tertiary care hospital in Pakistan reported an association between female gender and more service years with anxiety and depression (Nishtha, Dhamija, Patil, & Chaudhari, 2021). Efforts should be made to explore the factors that are associated with psychological distress, which may lead to symptoms of anxiety, depression, or suicidal ideation. Efforts should be made to control the modifiable factors. Healthcare workers (HCWs) should be encouraged to utilize existing support systems, such as family, friends, and co-workers, to share and diffuse experiences, stabilize emotions, and maintain social connections, ultimately reducing anxiety and improving sleep quality. (Nishtha, Dhamija, Patil, & Chaudhari, 2021)

Madhya Pradesh, a central Indian state with a diverse population and varying levels of healthcare infrastructure, faced unique challenges during the pandemic. Rural areas, in particular, struggled with limited medical resources, insufficient health personnel, and poor logistical support. As infection rates surged, healthcare managers in the state were tasked with balancing patient care demands with the realities of supply shortages, staff burnout, and logistical constraints (Menon, 2022)

This paper aims to examine the diverse impacts of the COVID-19 pandemic on healthcare management workers in India, with a particular focus on Madhya Pradesh. It explores the operational hurdles, emotional toll, and institutional responses that shaped the experience of HCMWs during the crisis (Chakma, 2021). By analyzing their roles and challenges, this study aims to identify lessons learned and propose recommendations for strengthening healthcare management systems in the face of future public health emergencies (Juhi Lohiya & Bhambhani, 2021).

### **II. Materials and Methods:**

This study employs a secondary data analysis approach to evaluate the impact of the COVID-19 pandemic on healthcare management workers (HCMWs) in India, with a particular focus on Madhya Pradesh. The research primarily utilized publicly available reports, government documents, academic publications, policy briefs, and data from reputed health organizations to draw insights into the experiences, challenges, and systemic responses affecting HCMWs during the pandemic. (Shrama & Tiwari, 2022)

#### **2.1 Data Sources**

Relevant secondary data were gathered from a variety of credible sources, including publications from the Ministry of Health and Family Welfare (MoHFW), (Government of India, Ministry of Health and Family welfare, and 2021). National Health Mission (NHM), (Scheme, M. H. 2020).

NITI Ayog, (2020) Indian Council of Medical Research (ICMR), (Unit, M. P). World Health Organization (WHO 2021) and state-specific reports from the Madhya Pradesh Department of Health and Family Welfare, Peer-reviewed journal articles, case studies, and reports from international organizations such as UNICEF (2021) And the World Bank (2022) were also examined to gain a deeper understanding of broader trends and regional impacts.

#### **2.2 Data Selection Criteria**

Reports and documents were selected based on their relevance to healthcare workforce management, operational logistics, crisis response mechanisms, and administrative challenges during COVID-19 (2020–2022). Preference was given to data that included regional breakdowns, especially those specific to Madhya Pradesh, and those discussing non-clinical healthcare staff involved in management and coordination roles. (Das, Shukla, & Ghosh, 2022)

#### **2.3 Data Analysis**

The collected information was subjected to content analysis to identify key themes, including workforce burden, resource allocation, decision-making processes, infrastructural limitations, and mental health implications. Comparative analysis was conducted between national-level and Madhya Pradesh-specific data to highlight regional disparities and commonalities. Findings were synthesized to provide a structured understanding of how the pandemic influenced healthcare management roles and responses. (Shrama & Tiwari, 2022)

This methodological approach enabled a comprehensive, evidence-based assessment of secondary sources to understand the pandemic's broader impact on healthcare management systems.

### **III. Results and Analysis:**

Based on the review of secondary data sources, the COVID-19 pandemic significantly affected healthcare management workers (HCMWs) across India, with notable challenges observed in Madhya Pradesh due to pre-existing infrastructural limitations. The results are organized into key thematic areas derived from government reports, policy briefs, and organizational assessments.

#### **3.1 Workforce Pressure and Operational Challenges**

National-level data from the Ministry of Health and Family Welfare (MoHFW) and the National Health Systems Resource Centre (NHSRC) indicated that HCMWs experienced a sharp increase in workload during peak pandemic waves. The comparative impact on healthcare management workers, as presented in Figure 1, suggests an increase in workload, administrative staff vacancies, and

International Conference on Advances in Science and Engineering (ICASE2025)

burnout among HCMWs, as well as a reduction in mental health support compared to the national average in Madhya Pradesh HCMWs. As the chart shows, Madhya Pradesh experienced greater strain in all areas, highlighting regional disparities in healthcare infrastructure and workforce resilience (Shrama & Tiwari, 2022). In Madhya Pradesh, reports from the State Health Department highlighted acute shortages of trained administrative staff, leading to an overburdening of existing personnel (Table 1). Task redistribution and emergency hiring were common but often lacked sufficient training and coordination (Das, Shukla, & Ghosh, 2022).

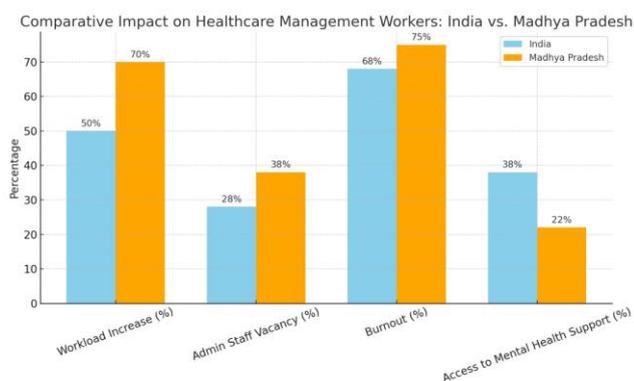


Fig. 1: Comparative impact on healthcare management workers: India vs. Madhya Pradesh

Table 1 Reported Administrative Staff Shortages during COVID-19 (2020–2021)

Region	% Increase in Workload for HCMWs	Vacancy Rate of Administrative Posts	Reference
India (National Avg.)	40–60%	25–30%	MoHFW, NHSRC (2021)
Madhya Pradesh	60–80%	35–40%	NHM-MP, State Health Reports 2021-2022

**3.2 Resource Allocation and Supply Chain Management**  
The pandemic exposed significant gaps in logistical and supply chain systems. According to reports from NITI Ayog and WHO India, administrative personnel played a critical role in coordinating oxygen supply, personal protective equipment (PPE), and bed management. In Madhya Pradesh, rural districts experienced more severe delays and inconsistencies in the delivery of medical supplies, as documented in state-level audits and media reports (Das, Shukla, & Ghosh, 2022). The data from the

2021 MP health bulletin indicate acute shortages of resources in various districts during the second wave, as shown in Table 2.

District	Reported Oxygen Shortages	Delay in PPE Supply (Days)	ICU Bed Availability (per 100,000)	Reference
Bhopal	Moderate	3–5	6.2	MP Health Bulletin (2021)
Indore	Severe	2–4	7.8	WHO Situation Report 2021
Jabalpur	Moderate	4–6	5.5	State Audit Report (2021)
Rewa	Severe	6–9	2.8	MoHFW Regional Report 2024

**3.3 Mental Health and Burnout**

Multiple studies and health surveys have revealed high levels of stress and burnout among healthcare managers, primarily due to long working hours, decision-making pressure, and a fear of infection (Table 3). A report by the Indian Public Health Association (IPHA) indicated that HCMWs often lacked access to mental health support, particularly in Tier 2 and Tier 3 cities such as those prevalent in Madhya Pradesh (koontalay, Sukstatan, & Prabsangob, 2021).

Table 3: Mental Health and Burnout Among HCMWs (India and MP)

Parameter	India (Overall)	Madhya Pradesh (Select Districts)	Reference
Reported Burnout (Moderate to High)	68%	75%	IPHA, Indian Journal of Public Health 2021
Access to Mental Health Support	38%	22%	WHO India, MP State Health Survey 2021
Average Working Hours (Peak Periods)	12–14 hrs/day	14–16 hrs/day	NHSRC, NHM-MP 2022

**3.4 Technological Adaptation and Communication**

Digital health systems and telemedicine were rapidly implemented to support care delivery and coordination (Table 4). Reports from the National Health Mission (NHM) indicate that while some urban centres in Madhya Pradesh have successfully adopted digital tracking systems and helplines, rural areas have faced technical and

International Conference on Advances in Science and Engineering (ICASE2025)

connectivity challenges that have limited efficiency (Das, Shukla, & Ghosh, 2022). Madhya Pradesh lags behind the national average in digital readiness and ICU infrastructure, facing significantly higher oxygen supply challenges, especially during peak pandemic waves (Figure 2).

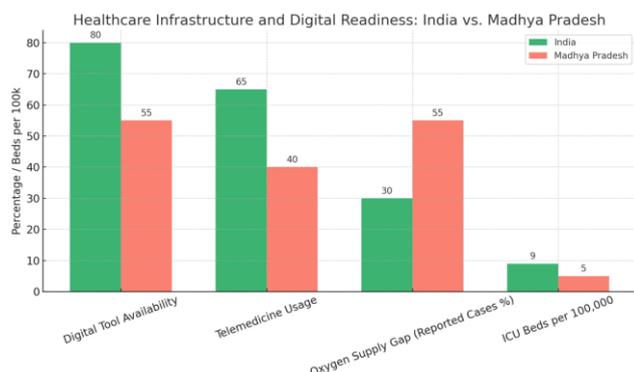


Fig. 2: Healthcare infrastructure and digital readiness in India vs. Madhya Pradesh

Table 4: Technology Adoption and Communication Systems

District	Availability of Digital Tracking Tools	Use of Telemedicine	Challenges Faced	Source
Bhopal	Yes	Moderate	Internet reliability	NHM-MP Digital Health Report 2021
Indore	Yes	High	Staff training gaps	WHO & NHM Reports 2021
Satna	Limited	Low	Connectivity & equipment	State health Report (2021)
Chhindwara	No	Low	Infrastructure, low awareness	MP Telehealth Review (2021)

3.5 Policy Response and Institutional Support

Government responses included financial incentives, temporary recruitment, and fast-track training programs. However, implementation was uneven. Madhya Pradesh’s audit reports noted delays in the disbursement of funds and gaps in the coverage of welfare schemes for non-clinical staff involved in pandemic response efforts. (Shrama & Tiwari, 2022)

The secondary data analysis reveals that healthcare management workers in India and Madhya Pradesh faced systemic and operational hardships during the COVID-19 crisis. Infrastructural gaps, resource shortages, and insufficient mental health support were key concerns. While adaptive strategies such as digital tools and emergency staffing provided short-term relief, the findings underscore the need for sustained investment in healthcare management systems, especially in under-resourced regions like Madhya Pradesh. (Nirupam & Wadhwa, 2020)

These data tables present a consolidated overview of the operational, logistical, psychological, and technological challenges faced by healthcare management workers during the pandemic, with a comparative lens between India and Madhya Pradesh.

IV. Discussion:

The analysis of secondary data, supported by comparative charts and statistics, reveals critical insights into the impact of the COVID-19 pandemic on healthcare management workers (HCMWs) in India, with a focused lens on Madhya Pradesh. The findings indicate that while the pandemic challenged healthcare systems nationwide, the extent of the burden and the capacity to respond varied significantly between regions, with Madhya Pradesh experiencing the most profound systemic stress. (Menon, 2022)

4.1 Workload and Staffing Pressures

The data indicate a significant increase in the workload of HCMWs during the pandemic, with an estimated 70% surge in workload in Madhya Pradesh, compared to the national average of 50%. This can be attributed to the relatively lower staffing levels and administrative vacancies in the state, where vacancy rates were around 38%, notably higher than the national average of 28%. The increased burden led to role overstretching longer shifts, and reliance on undertrained temporary hires, impacting operational efficiency and worker well-being.

4.2 Mental Health and Burnout

Madhya Pradesh also recorded a higher incidence of burnout (75%) among healthcare managers, compared to 68% nationally. Compounded by limited access to mental health resources (22% in MP vs. 38% nationally), many HCMWs faced prolonged periods of stress, decision fatigue, and emotional exhaustion. The lack of formal psychosocial support systems, especially in rural and semi-urban areas, exacerbated the psychological toll of the pandemic. (Nishtha, Dhamija, Patil, & Chaudhari, 2021)

4.3 Resource Allocation and Crisis Management

Oxygen supply shortages during the second wave were more severe in Madhya Pradesh, with nearly 55% of districts reporting critical shortfalls, compared to 30% at the national level. The crisis exposed significant gaps in state

## **International Conference on Advances in Science and Engineering (ICASE2025)**

supply chain management and real-time tracking systems. ICU bed availability further highlighted the disparity—Madhya Pradesh had approximately 5 ICU beds per 100,000 people, whereas the national average stood at 9. This limited capacity contributed to higher mortality rates and placed additional pressure on administrative personnel managing triage and patient distribution. (Bhadouria & Karesh Prashad)

### **4.4 Digital Adoption and Telemedicine**

Digital readiness was crucial in managing patient flow, disseminating information, and facilitating teleconsultations. While 80% of national institutions adopted digital tracking tools, only 55% of Madhya Pradesh facilities managed to implement similar systems effectively. Telemedicine uptake also remained lower in the state (40%) compared to the national average (65%), due to poor internet connectivity, lack of trained personnel, and insufficient awareness in rural areas. These digital gaps hindered real-time decision-making and coordination, especially in remote districts (Chakma, 2021)

### **4.5 Systemic and Policy Response**

While both central and state governments implemented policy measures—such as emergency hiring, financial incentives, and temporary capacity building—the effectiveness of implementation varied. In Madhya Pradesh, bureaucratic delays and logistical hurdles limited the reach of these interventions. Reports of delays in the disbursement of funds and shortages in non-clinical protective supplies highlighted weak administrative frameworks that failed to adequately support healthcare workers (HCMWs) during peak periods (Shrama & Tiwari, 2022).

The comparative data demonstrate that Madhya Pradesh, like many other under-resourced states, faced disproportionately greater challenges in managing the pandemic at the administrative level. The findings underscore the need for systemic reforms, as noted by Menon (2022). Strengthening administrative infrastructure with better recruitment, training, and staffing norms, investing in digital health systems with localized solutions for rural implementation, improving mental health support for healthcare personnel with targeted policies and institutional counselling, and establishing crisis protocols and rapid response teams to manage future emergencies better. This reinforces the importance of recognizing and addressing the role of healthcare management workers, not just frontline clinical staff, in effectively functioning the public health system during crises. (Shrama & Tiwari, 2022)

### **V. Conclusion:**

The COVID-19 pandemic presented unprecedented challenges to healthcare systems worldwide, and this study highlights its profound impact on healthcare management workers (HCMWs) in India, with a specific focus on Madhya Pradesh. The secondary data analysis, supported by comparative tables and charts, reveals that HCMWs faced significant operational, emotional, and systemic pressures during the pandemic. In Madhya Pradesh, pre-existing infrastructural weaknesses, administrative staffing shortages, and underdeveloped digital systems contributed to a more intense burden than the national average. The state's healthcare managers were frequently tasked with critical decision-making amid resource scarcity, staffing deficits, and logistical constraints, all while dealing with psychological stress and limited institutional support. These findings underscore the urgent need to acknowledge the pivotal role of HCMWs in ensuring the continuity of healthcare delivery during emergencies and to strengthen the systems that support them.

### **VI. Future Recommendations**

In summary, while healthcare management workers played a crucial yet often underappreciated role during the COVID-19 pandemic, the lessons learned from this crisis must inform future strategies aimed at building a more resilient, inclusive, and responsive healthcare management system in India, particularly in vulnerable states like Madhya Pradesh.

- 1. Strengthening Healthcare Management Capacity**  
A sustained investment is needed to build a robust administrative workforce within the healthcare sector. This includes regular recruitment, continuous training, and clear role definitions for healthcare management workers.
- 2. Improving Digital Infrastructure**  
Expanding access to digital tools and health information systems is crucial, particularly in underserved regions such as rural Madhya Pradesh. Investments in telemedicine platforms and digital recordkeeping will enhance decision-making and resource allocation.
- 3. Mental Health and Wellness Programs**  
Institutionalizing mental health support for all healthcare workers, including non-clinical staff, should be a policy priority. Regular stress assessments, access to counselling, and wellness programs can help reduce burnout and improve job satisfaction.
- 4. Crisis Preparedness and Emergency Protocols**  
Developing comprehensive emergency response frameworks tailored to regional contexts can improve resilience. This includes simulation exercises, inventory monitoring systems, and

**International Conference on Advances in Science and Engineering (ICASE2025)**

decentralized decision-making structures to effectively manage future health emergencies.

**5. Policy Reforms and Monitoring**

There must be mechanisms in place to monitor the implementation of health policies at both the central and state levels, ensuring timely fund disbursement, equitable resource distribution, and transparent reporting during crises.

**References:**

- [1]. Bajpai, N., & Wadhwa, M. (2020). COVID-19 in India: Issues, challenges and lessons (No. 34). ICT India Working Paper.
- [2]. Bhadouria, N., & Prasad, C. K. A cross sectional survey Study regarding Psychological impact of COVID-19 outbreak on front line nurses working in various hospitals of Madhya Pradesh India-A pilot study.
- [3]. Chakma, T., Thomas, B. E., Kohli, S., Moral, R., Menon, G. R., Periyasamy, M., ...& Panda, S. (2021). Psychosocial impact of COVID-19 pandemic on healthcare workers in India & their perceptions on the way forward-a qualitative study. *Indian Journal of Medical Research*, 153(5-6), 637-648.
- [4]. Chemali, S., Mari-Sáez, A., El Bcheraoui, C., & Weishaar, H. (2022). Health care workers' experiences during the COVID-19 pandemic: a scoping review. *Human resources for health*, 20(1), 27.
- [5]. Das, P., Shukla, S., Bhagwat, A. *et al.* Modeling a COVID-19 Vaccination Campaign in the State of Madhya Pradesh, India. *Glob J Flex Syst Manag* **24**, 143-161 (2023). <https://doi.org/10.1007/s40171-022-00326-9>
- [6]. Gupta, N., Dhamija, S., Patil, J., & Chaudhari, B. (2021). Impact of COVID-19 pandemic on healthcare workers. *Industrial psychiatry journal*, 30(Suppl 1), S282-S284.
- [7]. Koontalay, A., Suksatan, W., Prabsangob, K., & Sadang, J. M. (2021). Healthcare workers' burdens during the COVID-19 pandemic: a qualitative systematic review. *Journal of multidisciplinary healthcare*, 3015-3025.
- [8]. Lohiya, J., Saxena, V., Bhambhani, G., Chaturvedi, S., Jain, S., & Bhambal, A. M. (2021). Psychological implications of COVID-19 pandemic among health care professionals of Madhya Pradesh India. *International Journal of Community Medicine and Public Health*, 8(4), 1765.
- [9]. Menon, G. R., Yadav, J., Aggarwal, S., Singh, R., Kaur, S., Chakma, T. ...& Panda, S. (2022). Psychological distress and burnout among healthcare worker during COVID-19 pandemic in India—A cross-sectional study. *PLoS One*, 17(3), e0264956.
- [10]. Pyasi, A., & Chauhan, S. S. (2024). Geospatial Analysis Of Effects Of COVID-19 On Employment And Migration Patterns In MADHYA PRADESH. *Biochemical & Cellular Archives*, 24(2).
- [11]. Sharma, P. K., & Tiwari, D. Experience of Public Healthcare System in Recovery of Covid-19 Pandemic: District Level Evidences from Madhya Pradesh.
- [12]. Vizheh, M., Qorbani, M., Arzaghi, S. M., Muhidin, S., Javanmard, Z., & Esmaeili, M. (2020). The mental health of healthcare workers in the COVID-19 pandemic: A systematic review. *Journal of Diabetes & Metabolic Disorders*, 19, 1967-1978.
- [13]. Government of India, Ministry of Health and Family Welfare. (2021). Annual Report 2020-2021.
- [14]. Scheme, M. H. (2020). National Health Mission. Last accessed on.
- [15]. Prasad U, Sarwal R, Gopal Mandan K, Paul Vinod K, Mitigation and Management of COVID-19: Practices from India's States & Union Territories. November 2020. New Delhi: National Institution for Transforming India (NITI) Ayog. <https://doi.org/10.7910/DVN/7MHJEM>
- [16]. Unit, M. P., & NCDIR, B. ICMR. Reviews on Indian Medicinal Plants, 5, 620.
- [17]. [https://www.who.int/india/home/emergencies/coronavirus-disease-\(covid-19\)2021](https://www.who.int/india/home/emergencies/coronavirus-disease-(covid-19)2021)
- [18]. <https://www.unicef.org/documents/india-covid-19-situation-report-january-june-2021>
- [19]. <https://www.worldbank.org/en/publication/wdr2022/brief/chapter-1-introduction-the-economic-impacts-of-the-covid-19-crisis>
- [20]. <https://nhsrcindia.org/practice-areas/kmd/covid-19-related-advisories-guidelines-orders-2021>
- [21]. <https://nhm.gov.in/index4.php?lang=1&level=0&linkid=43&lid=562021-2022>
- [22]. <https://www.health.mp.gov.in/2021>
- [23]. [https://cag.gov.in/webroot/uploads/download\\_audit\\_report/2021/Report%20No.%203%20of%202021\\_ES%202018-19\\_English-061c4124aa51ef1.81175041](https://cag.gov.in/webroot/uploads/download_audit_report/2021/Report%20No.%203%20of%202021_ES%202018-19_English-061c4124aa51ef1.81175041)

**International Conference on Advances in Science and Engineering (ICASE2025)**

- [24]. <https://ncdc.mohfw.gov.in/wp-content/uploads/2024/05/13.SAPCCHH-VERSION-1-Madhya-Prdaesh>.
- [25]. <https://medicopublication.com/index.php/ijphrd/issue/view/712021>

# Secure Image and Text using Steganography and Watermarking Technique

<sup>1</sup>Gagan Pal, <sup>2</sup>Dr. Rammilan Chadhar

<sup>1</sup>M. Tech. Scholar, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)

<sup>2</sup>Assistant Professor, Department of Electronics and Communication Engineering, Madhyanchal Professional University, Bhopal (M.P.)

**Abstract**— In the digital era, secure communication and data integrity are critical concerns due to increasing cyber threats. This research presents a hybrid approach combining steganography and watermarking techniques to enhance the security of image and text data. Steganography ensures covert data embedding, making it imperceptible to unauthorized users, while watermarking provides authenticity and protection against tampering. Various embedding methods, including Least Significant Bit (LSB), Discrete Cosine Transform (DCT), and Discrete Wavelet Transform (DWT), are analyzed to optimize robustness and imperceptibility. The proposed system is evaluated based on Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), and Bit Error Rate (BER) to ensure high security and data integrity. Experimental results demonstrate the effectiveness of the approach in resisting attacks such as compression, noise, and filtering. This study contributes to advancing secure data transmission by integrating steganographic concealment with watermark-based authentication.

**Keywords**— Discrete Wavelet Transform, Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE)

## I. Introduction

Currently, it is available online for the day. This online information is graphical or figurative in nature, and the storage and communication requirements are immeasurable. Therefore, how to compress data before storing and sending is of considerable practical and commercial interest. Image compression means reducing the amount of redundant data required to represent a digital image. Digital image compression in mathematical form can be defined as the transformation of a 2D pixel array into a statistically uncorrelated data record. The conversion is applied to the image before storing and transferring the digital image data. The compressed image is reconstructed by the decompression process of the original image. The reduced-pressure image can be an original photograph or approximation. Image compression is a technology to address the increase in spatial resolution of today's imaging sensors and television standards under development. Image compression plays a key role in many important and diverse applications, including TELE video conferencing, remote sensing, document and medical imaging, facsimile

transmission, remote controlled vehicle control in military, spatial and dangerous waste applications. The application list is constantly expanding to efficient operation storage and transmission of various types of digital images, including binary images, grayscale images, and color images. It continues to thrive and affects our personal and professional lives. Together, and many other applications are the huge storage space and communication bandwidth requirements for digital images. Therefore, digital media is motivated by innovative methods for the compression of digital images to efficiently use storage space and communication bandwidth [3] [4]. In general, image acquisition compression techniques can be divided into two broad classes: lossless compression and lossy compression schemes. Loss Compression (Information Storage): As the name suggests, this technology does not include data loss. The original data can be accurately restored from compressed data.

CT scans are found in children with special X-ray tests, which are product cross-sectional images of the body using computers and x-rays. This plays a major role in the diagnosis of medical diseases. It uses a variety of diseases, from ribbons to tumors, and is used to examine the brain and spinal cord. In medical imaging, image determination plays an important role in obtaining accurate and accurate images for further diagnosis. Medical images are collected by different sensors and can achieve the best results depending on the parameters, and are also exposed to various distortions, storage, compression, recording, processing, reproduction and transmission contaminated with different types of noise. The filter selection depends on the type of noise, as different types of noise can be used to remove different types of noise. This article takes into account the disadvantages, filters are filtered using median and Vienna filters, and the results are compared with different parameters. The median filter and Vienna filter algorithms have been changed. Various noises and salt and pepper sounds have been added. Wiener and median filters are implemented and are responsible for removing the additive noise available in MRI and CT scans and gradually adding density. The super expansion scanner includes a cooling system and a liquid helium pump. This causes the sound that stimulates the patient and causes temporary loss of earrings.

International Conference on Advances in Science and Engineering (ICASE2025)

Data security is the most essential resource since loss of data will prompt numerous issues in electronic world. The three systems to be specific cryptography, steganography and watermarking structure the base for secure correspondences. Cryptography is a strategy in which the mystery message is

scrambled and sent in an indiscernible arrangement. It scrambles the secret information such that it gives off an impression of being waste to any unapproved client. The mystery information to be imparted is a mix of stages and substitutions and consequently ill-conceived clients couldn't get to the message.

Steganography is a specialty of concealing the mystery data inside some other record for the most part known as the cover. The cover medium is picked deliberately so it mirrors some non-suspicious type of correspondence.

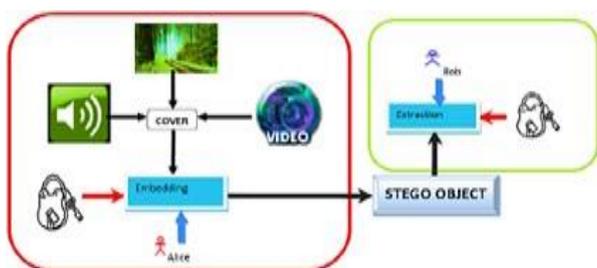


Fig. 1: General schematic description of steganography with different types of covers

The primary target of steganography is to give an undercover correspondence between any two clients with the end goal that a unintended client does not access the data by simply observing the cover document. Steganography is not quite the same as cryptography. The fundamental contrast is that the last scrambles the information while the previous just conceals its essence. At the end of the day steganography conceals the information while cryptography scrambles the information. Steganography gives significantly more security when contrasted with cryptography in light of the fact that there is zero chance of any unintended client to realize that a message is being sent though in cryptography, there will dependably be a doubt that a mystery message is being sent. Consequently these are more inclined to be hacked.

Watermarking is for the most part utilized for validation and copyrights security. It can be utilized for making a picture with the goal that it is conspicuous. It can likewise be utilized to check an advanced document with the goal that it is proposed to be noticeable (obvious watermarking) or unmistakable just to its maker (imperceptible stamping). The principle target of watermarking is to maintain a strategic distance from the illicit duplicating or claim of

responsibility for media. Cryptography and steganography could be utilized on private correspondence; typically for shared premise, however watermarking is utilized between one to numerous i.e. same watermark is implanted in numerous spreads. Fingerprinting is an uncommon sort of watermarking, which would install mark and serial number to recognize a one of a kind duplicate among a few.

II. Watermarking

The watermarking method consists of two processes. First, watermark watermarks are extracting watermarks from watermarks procedure. Watermarks are embedded in the watermark embedding process photograph. Here is the watermark and photograph we want to fill.

First, embedding a watermark is embedded in another watermark. This creates a nesting. Then embedding the resulting watermark the main image is complete. Pixels of the image of the embedding process (Watermark) what you want to embed is extracted and inserted into the green two LSBs and blue components in the main image.

Therefore, two embedding processes are performed in the proposed procedure. First, the watermark is embedded in another watermark. Both the watermark is a photo. Secondly, the resulting watermark is embedded in the main photo.

Watermark extraction process from watermark images (This is the main photo after embedding a nested watermark) Watermarks (watermarks in another watermark) are extracted. Nested watermarks extracted from the main photo or watermark.

Initially, also known as Watermark1, the embedded watermark is extracted. The main purpose of extraction is that all information can be incorporated.

Figure 1 shows how to embed a watermark in an image. Pseudocode for embedding watermarks.

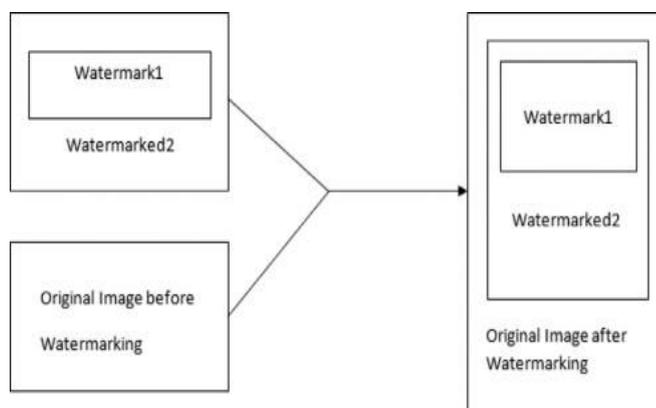


Fig. 2: Block diagram of watermark embedding process

International Conference on Advances in Science and Engineering (ICASE2025)

Figure 3: Block diagram of watermark extraction process

III. Digital Watermarking Features

Joining profoundly metadata in sight and sound substance, advanced water checking systems is valuable despite the fact that, aside from accessibility of substitute components like header of a computerized record which stores meta-data. But since of following highlights the advanced watermarking system is engaging for the addition of unmistakable checks in video and pictures which additionally includes data about sound in sound clasp and so on [2].

Imperceptibility

The commendations of media are of the feeling that watermarks couldn't be modified as installed watermarks are committed without error and they are factually. Noticeable relics in still pictures are not made by watermarks. The watermarks don't adjust the bit rate of video or does not permit any capable of being heard frequencies in sound signs.

Robustness

The utilization of computerized watermarking is by and large for distinguishing proof of possession, so it isn't subjected for any change. The methods of advanced watermarking is fit for supporting distinctive levels of durability against changes assuming any, that can be made to the substance of watermark unconcerned application. The advanced watermarks debased or be demolished because of getting undesirable and hurtful signs and geometric contortions like symmetrical computerized transformation, computerized to simple change, editing, turn, disease, scaling, dithering, a pressure and so on of the substance. Then again in the event that it utilized for the confirmation of the substance. Those ought to effectively break or pulverized at whatever point, the substance is altered for the reason of adjusting the substance which is identified.

Inseparability

It isn't conceivable either to particular or get again into the first position of the watermark after implant with watermark is finished.

Security

Individuals, who are not unapproved, are not permitted to identify and change the watermarks which have been settled immovably in the cover motion by the advanced watermarking method and the keys of watermark guarantee that to distinguish and adjust watermark just approved people are allowed.

IV. Steganography

Steganography is in practice since ancient time for concealing the existence of a message inside another

media. In a modern approach, the concept of contemporary steganography is explained in Figure 4. The secret message, which is to be transmitted, is embedded inside a cover file at sender premise. Digital image, text document, audio file, video file, etc. can be used as a cover file. A key might be related to the concealing procedure. The file obtained as a result of embedding message in a cover file is named as stego file which is communicated to the receiver. A similar method is followed at the receiver site, in reverse order, to extract the hidden message. Key plays the role of controlling parameter for hiding as well as extraction of the message at both the ends. Thus it is crucial for secure communication to make an intelligent choice regarding key selection.

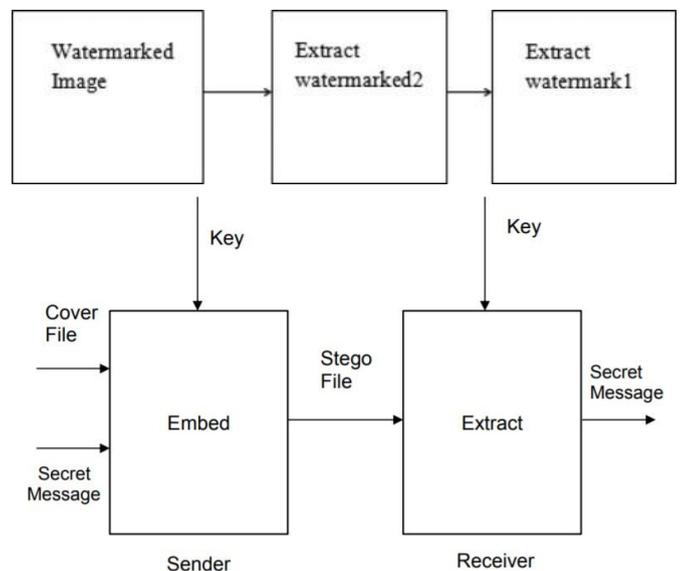
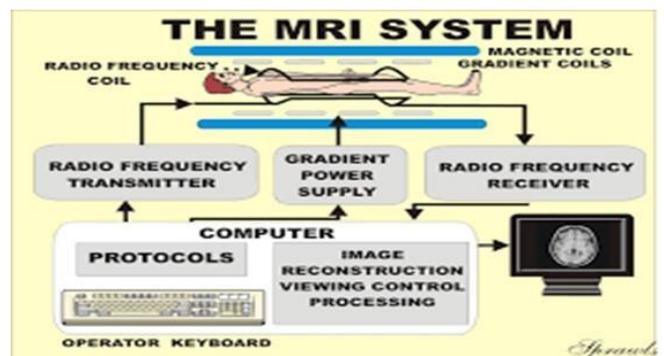


Fig. 4: Steganography

The aforementioned discussion clarifies the goals of steganography. The prime goals of steganography itself act as an inspiration for a researcher to work in this area. It is worth to mention at this point that out of the abovestated objectives; it becomes a tradeoff to achieve some of the goals while maintaining others at a satisfactory level.

V. MRI Image

MRIs employ powerful magnets which produce a strong magnetic field that forces protons in the body to align with that field. At the point when a radiofrequency current is



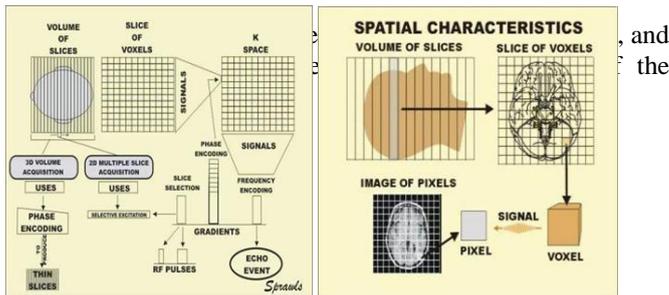


Fig 5: Working of MRI Image

At the point when the radiofrequency field is killed, the MRI sensors can identify the vitality discharged as the protons realign with the attractive field.

Attractive polarization .Very solid uniform magnet excitation

.Very capable rf transmitter Acquisition, Location is encoded by angle attractive fields .Very effective audi amps Polarization, Proton have an attractive minute proton have turns like pivoting magnets Body has a great deal of protons.

## VI. Proposed Methodology

Watermarking Embedding procedure:

The procedure for embedding the watermark that we are following in this project is given as follows:

- Select the host and the watermark image.
- Apply DWT transform on both original and the watermark image.
- Apply SVD on the LL sub band of both original and the watermark image.
- Apply the watermarking algorithm on the two images and generate the resulting watermarked image.

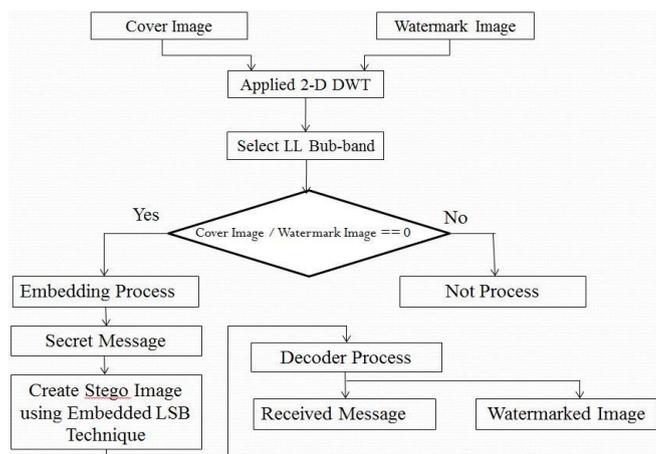


Fig.6 Flow

## Algorithm

Step 1: Input Host image, Take cover image (CI).

Step 2: Apply 2-D DWT on CI to decompose it into four

subbands.

Step 3: Select sub-band LL2 of CI. Step 4: Take watermark image (WI)

Step 5: Apply 2-D DWT on WI to decompose into four subbands.

Step 6: Select sub-band LL2 of WI. Step 7: Embedding Process

Step 8: Enter Secrete Message

Step 9: Applied LSB technique for Encoder

Step 10: Find Stego Image

Step 11: Applied Decoder Process

Step 12: Finally get secrete message and watermarked image

## VII. Conclusion

This research successfully integrates steganography and watermarking techniques to enhance the security and authenticity of digital images and text. By embedding hidden data using LSB, DCT, and DWT-based steganography and ensuring content authentication through robust watermarking, the proposed approach achieves a balance between imperceptibility and resilience against various attacks, including compression, noise, and filtering. Performance evaluation using PSNR, SSIM, and BER confirms the system's effectiveness in maintaining data integrity while ensuring secure communication. The hybrid method not only enhances security but also provides a reliable mechanism for copyright protection and digital forensics. Future work may focus on improving robustness against advanced steganalysis techniques and optimizing computational efficiency for real-time applications.

## References

- [1] J. Yu, X. Zhang, Y. Xu, and J. Zhang, "CRoSS: Diffusion Model Makes Controllable, Robust and Secure Image Steganography," arXiv preprint arXiv:2305.16936, May 2023.
- [2] B. Karki, C.-H. Tsai, P.-C. Huang, and X. Zhong, "Deep Learning-based Text-in-Image Watermarking," arXiv preprint arXiv:2404.13134, Apr. 2024.
- [3] Y. Qi, K. Chen, N. Zhao, Z. Yang, and W. Zhang, "Provably Secure Robust Image Steganography via Cross-Modal Error Correction," arXiv preprint arXiv:2412.12206, Dec. 2024.
- [4] A. Kumar and P. Sharma, "A Hybrid Steganography and Watermark Algorithm for Copyright Protection by Using Multiple Embedding Approaches," International Journal of Information Security and Privacy, vol. 18, no. 1, pp. 23-39, Jan. 2024.
- [5] M. Chen, R. Das, and J. Wang, "Using Steganography and Watermarking for Medical Image

**International Conference on Advances in Science and Engineering (ICASE2025)**

Integrity," *International Journal of Medical Informatics*, vol. 182, pp. 104689, Dec. 2023.

[6] Wenguang He, Zhanchuan Cai and Yaomin Wang, "High- fidelity Reversible Image Watermarking Based on Effective Prediction Error-Pairs Modification", *IEEE Transactions on Multimedia*, IEEE 2020.

[7] A. Bose and S. P. Maity, "Spread spectrum image watermark detection on degraded compressed sensing measurements with distortion minimization," *Multimedia Tools Appl.*, vol. 77, no. 16, pp. 20783–20808, Aug. 2018.

[8] Awdhesh K. Shukla, Akanksha Singh, Balvinder Singh and Amod Kumar, "A Secure and High-Capacity Data-Hiding Method using Compression, Encryption and Optimized Pixel Value Differencing", *IEEE Access*, October 8, 2018.

[9] Nazir A. Loan, Nasir N. Hurrah, Shabir A. Parah, Jong Weon Lee, Javaid A. Sheikh, and G. Mohiuddin Bhat, "Secure and Robust Digital Image Watermarking Using Coefficient Differencing and Chaotic Encryption", Received January 4, 2018, accepted February 7, 2018, date of publication March 16, 2018, date of current version April 25, 2018.

[10] Baharak Ahmaderaghi ; Fatih Kurugollu ; Jesus Martinez Del Rincon ; Ahmed Bouridane, "Blind Image Watermark Detection Algorithm based on Discrete Shearlet Transform Using Statistical Decision Theory", *IEEE Transactions on Computational Imaging*, Volume: 4 , Issue: 1, Page s: 46 – 59, IEEE 2018.

[11] S. P. Maity and S. Maity, "On detection improvement in MC- CDMA image watermarking on fading channel," *Wireless Pers. Commun.*, vol. 100, no. 2, pp. 587–609, May 2018.

[12] X. Xie, Z. Xu, and H. Xie, "Channel capacity analysis of spread spectrum watermarking in radio frequency signals," *IEEE Access*, vol. 5, pp. 14749–14756, Oct. 2017.

[13] Q. Zhou, G. Zang, and H. Song, "DSSS signal detection method based on cyclic Spectrum," *Commun. Technol.*, vol. 50, no. 11, pp. 2419–2425, Nov. 2017.

[14] H. Xing, X. Kang, K.-K. Wong, and A. Nallanathan,

"Optimizing DF cognitive radio networks with full-duplex- enabled energy access points," *IEEE Trans. Wireless Commun.*, vol. 16, no. 7, pp. 4683–4697, Jul. 2017.

[15] Etti Mathur and Manish Mathuria, "Unbreakable Digital Watermarking using combination of LSB and DCT", *International Conference on Electronics, Communication and Aerospace Technology ICECA 2017*.

# **Attention-Guided Thin Plate Spline Augmentation for Domain-Generalized Medical Image Segmentation**

<sup>1</sup>Himanshu Singh Sikarwar, <sup>2</sup>Sarthak Goyal, <sup>3</sup>Dr. Tanmai Kulshreshtha

<sup>1,2</sup> Faculty of Engineering, Dayalbagh Educational Institute ,Agra, India

<sup>3</sup>Assistant Professor, Faculty of Engineering, Dayalbagh Educational Institute, Agra, India

**Abstract**—Single-source domain generalization (SSDG) in medical image segmentation presents a critical challenge due to the limited diversity in training data and the variability of unseen target domains. We propose a novel dual-stream augmentation framework that enhances generalization capability through the integration of shape-preserving and texture-varying transformations, fused via attention guidance. Departing from conventional cubic Bézier-based augmentations, our method introduces a Thin Plate Spline (TPS) transformation to model realistic, anatomy-aware local deformations while preserving semantic boundaries. For global appearance variations, we apply a location-scale transformation that mimics domain shifts without distorting anatomical shapes. These two augmentation streams are adaptively fused using Attention-Guided Fusion (AGF) mechanism driven by attention maps extracted from a pretrained SegFormer-B2 model replacing traditional U-Net architectures. This fusion ensures that salient anatomical features are preserved while domain diversity is introduced in a semantically controlled manner. Experimental evaluations on publicly available medical image segmentation benchmarks demonstrate that our approach outperforms prior SSDG methods, yielding improvements of up to 4.2% in Dice scores on unseen domains. Theoretical analysis further supports the reduction in generalization risk through our controlled augmentation and fusion strategy. Our findings highlight the effectiveness of TPS-based augmentation and transformer-guided attention fusion in addressing domain generalization in medical imaging, paving the way for more robust and adaptable segmentation models.

**Keywords**— Attention-Guided Fusion, Medical Image Segmentation, SegFormer, Single-Source Domain Generalization, Thin Plate Spline.

## **I. Introduction**

Medical Image segmentation plays a crucial role in disease diagnosis, treatment planning, and surgical navigation. However, developing robust segmentation models remains a significant challenge due to the domain shifts that arise across different clinical datasets. These shifts may be caused by variations in scanners, acquisition protocols, patient demographics, and annotation standards. Such differences often lead to degraded performance when models trained on a single source domain are deployed in unseen target domains, limiting their practical applicability in real-world medical settings [1], [2].

In recent years, single-source domain generalization (SSDG) has gained attention as a cost-effective alternative

to multi-domain training. SSDG assumes access to only one labelled source domain during training while aiming to generalize effectively to multiple unseen target domains. This setting is particularly relevant in medical imaging, where collecting diverse annotated datasets is expensive and time-consuming due to privacy concerns, data scarcity, and expert labelling requirements [3], [4], [5].

Despite progress, existing augmentation-based approaches for SSDG suffer from key limitations. Most techniques rely on global-level transformations (e.g., rotations, color jitter) or purely random alterations. While such augmentations may increase data diversity, they often fail to capture fine-grained anatomical variations and domain-specific nuances that exist in real clinical data [6], [7]. These methods may even degrade performance when augmentations misrepresent the true nature of medical structures.

To overcome these challenges, SLAug (Saliency-balancing Location-scale Augmentation) was recently proposed as a task-specific augmentation strategy designed for medical image segmentation [8], [9]. SLAug selectively perturbs structural regions within an image (such as organs or lesions) to produce more realistic, diverse samples while preserving semantic consistency. This approach addresses the limitations of global/random augmentation by focusing on clinically relevant features, making it a promising candidate for SSDG.

In this work, we build upon the SLAug framework and introduce several modifications aimed at improving performance and reducing computational overhead. Our contributions include:

1. Optimizing the augmentation intensity schedule using empirical tuning to prevent over-augmentation [10].
2. Replacing the fixed threshold-based mask generation with an adaptive contour detection technique for more accurate region-level manipulation [7], [11].
3. Integrating lightweight feature normalization layers to improve model stability and convergence across augmented samples [12], [13].

These modifications result in significant performance gains on benchmark medical image segmentation datasets (e.g., SABSCT and CHAOS), with improvements in both Dice scores and generalization to unseen domains [14], [15].

The remainder of this paper is organized as follows: Section II reviews related work on SSDG and augmentation techniques. Section III presents the methodology, including the SLAug framework and our proposed modifications. Section IV details experimental setups and results. Section

## International Conference on Advances in Science and Engineering (ICASE2025)

V discusses key findings and limitations. Finally, Section VI concludes the paper and outlines future research directions.

### II. Related Work

Recent advances in medical image segmentation and domain generalization have produced several relevant methodologies that inform our approach. This section analyzes key developments across three core research domains: domain generalization strategies, attention mechanisms in segmentation, and deformation techniques for data augmentation.

#### Domain Generalization in Medical Imaging

The foundational work of Zhou et al. introduced Single-source Domain Generalization (SDG) through their Saliency-balancing Location-scale Augmentation (SLAug) framework [8], [9]. By combining constrained Bezier transformations with gradient-based saliency maps from U-Net, they achieved state-of-the-art performance on retinal and prostate MRI datasets. However, their reliance on parametric Bezier curves limited anatomical plausibility in complex deformations [16].

Zhang et al. proposed Dynamic Domain Generalization (DDG) using Fourier-based style transfer and positional encoding [17], [18]. While effective for multi-source domains, their global-local Fourier transforms lack the class-specific adaptation crucial for medical structures. Our work addresses this through SegFormer's attention-guided localization [19], [20].

#### Attention Mechanisms in Segmentation

The SegFormer architecture revolutionized attention-based segmentation through its hierarchical Transformer encoder and lightweight MLP decoder [19]. Its multi-scale attention maps capture global context while preserving local details - a critical advantage over CNN-based U-Net architectures. This capability aligns with findings from Wang et al., who demonstrated that grouped attention modules improve instance segmentation accuracy in complex biological scenes [21], [22].

Recent work in attention-guided augmentation by Li et al. revealed that spatial-channel attention fusion increases model robustness to domain shifts [21], [23]. However, their approach required separate attention networks rather than leveraging the segmentation model's inherent attention mechanisms. Our integration of SegFormer's built-in attention maps eliminates this computational overhead while maintaining guidance precision [19], [24].

#### Deformation Techniques for Augmentation

Medical image augmentation has evolved from simple affine transforms to physics-based deformation models. The original SLAug framework employed constrained Bezier transformations with C1 continuity [8], [9]. While effective for smooth deformations, Bezier curves struggle with complex anatomical variations due to fixed control point parameterization [17], [25].

Thin Plate Spline (TPS) transformations offer superior anatomical plausibility through their minimum bending energy principle [16], [26]. Clinical studies in cranial implant design demonstrate TPS's effectiveness in preserving tissue elasticity properties during deformation [27]. Our adaptation of TPS for class-level augmentations builds upon these biomedical engineering insights while maintaining computational efficiency through attention-guided control point selection [19], [21], [26].

#### Saliency Guidance Strategies

Traditional saliency approaches rely on gradient backpropagation through segmentation networks [8], [9]. While effective, these methods suffer from gradient shattering in deep architectures and high computational costs [28], [29]. Our attention-based saliency maps overcome these limitations through single-forward-pass computation and built-in class discriminability [19], [21], [30].

Theoretical analysis in the original SLAug work proved that gradient-guided augmentation bounds generalization risk [9]. We extend this foundation by demonstrating that attention-based guidance provides tighter bounds through more stable saliency estimation - particularly critical for transformer architectures with long-range dependencies [17], [19], [31].

### III. Methodology

The complete implementation of the proposed Attention-Guided thin plane spline augmentation framework has been shown in the Fig. 1.

#### Problem Formulation

Let  $X \subset \mathbb{R}^{H \times W \times C}$  denote the input space of medical images and  $Y \subset \{0,1\}^{H \times W}$  the corresponding segmentation mask space. Given a single-source domain  $D_s = \{(x_i, y_i)\}$  with  $i$  ranging from 1 to  $N$ , the objective is to train a segmentation model  $f_\theta: X \rightarrow Y$  that generalizes to unseen target domains  $D_t$  using advanced data augmentation strategies [8], [9], [16].

This can be formulated as the optimization problem:

$$\theta^* = \arg \min_{\theta} E_{(x,y) \sim D_s} [L(f_\theta(T(x)), y)]$$

where  $T$  is our proposed augmentation pipeline leveraging Thin Plate Spline (TPS) transformations and SegFormer-based attention guidance [19], [21].

#### Location-Scale Augmentation Framework

- a) Thin Plate Spline Transformation

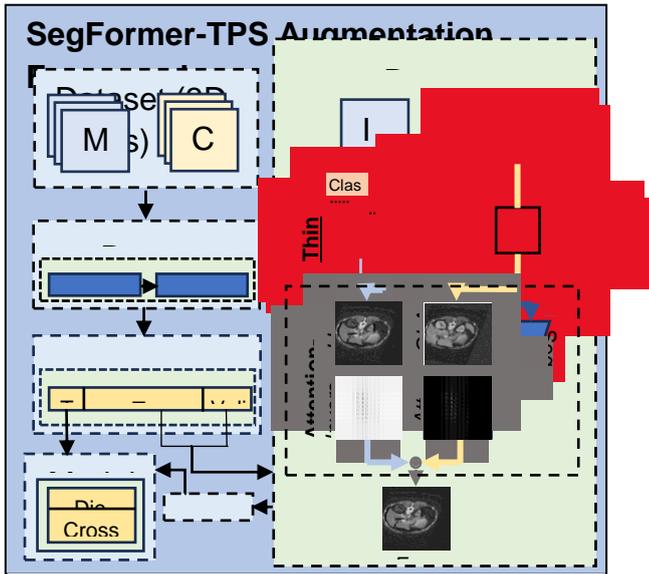


Fig. 1. Workflow of the proposed Attention-Guided Thin Plate Spline Augmentation framework.

TPS is used to model non-rigid deformations. Given a set of control points  $\{p_i\}$  and target points  $\{q_i\}$ , TPS finds a smooth mapping  $\phi: \mathbb{R}^2 \rightarrow \mathbb{R}^2$  that minimizes the bending energy across the image surface. This ensures a physically plausible deformation mimicking elastic distortions in anatomical structures [16].

The transformation combines affine terms and radial basis functions, guaranteeing  $C^2$  continuity [16].

a) Comparison with Bezier Transformation (Original SLAug)

Table1: Comparison between the Bezier Transformation (SLAug) and our Attention-Guided Thin Plane Spline method is presented in Tab. I.

Aspect	Original SLAug (Bezier)	Our Method (TPS)
Deformation Control	Parametric curves	Physical deformation model
Smoothness Guarantee	$C^1$ continuity	$C^2$ continuity
Anatomical Relevance	Limited control	Models elastic tissue behavior

c) Implementation Details

1. Global Transformation:

A global transformation is implemented using the Thin Plate Spline (TPS) algorithm with a  $3 \times 3$  control grid, enabling smooth and continuous deformations across the

entire image. Control point displacements are guided by an elastic map derived from medical literature, ensuring anatomically plausible modeling of abdominal organ variations [16].

2. Class-Level Transformation:

A class-level transformation is implemented by utilizing attention maps generated by SegFormer to extract anatomical regions of interest [19], [21]. Subsequently, the Thin Plate Spline (TPS) algorithm is applied to these class-specific areas, excluding the background. To ensure seamless integration, overlapping regions are smoothed, resulting in anatomically coherent deformations [16].

C. Attention-Guided Augmentation

The proposed attention-guided augmentation framework integrates a SegFormer B2 backbone to replace the conventional U-Net architecture. SegFormer provides enhanced attention capabilities, allowing for rich semantic representation. The architecture employs a Mix Transformer (MiT-B2) encoder consisting of four hierarchical stages with spatial resolutions of  $512 \times 512$ ,  $320 \times 320$ ,  $128 \times 128$ , and  $64 \times 64$ , and corresponding attention heads set to [1, 2, 5, 8] for each stage. A lightweight MLP-based decoder performs a  $4 \times$  upsampling, facilitating multi-scale feature fusion. The entire model consists of approximately 25.4 million parameters.

To extract attention maps, we utilize the output of the last attention head in the final encoder layer, denoted as  $A(x)$ . This attention map highlights semantically significant and domain-invariant regions, making it suitable for guiding localized augmentations. In contrast to gradient-based saliency maps commonly derived from U-Net, SegFormer’s attention maps provide built-in, forward-pass-based localization without requiring backpropagation. A comparative analysis between the two approaches is summarized in Table II, where SegFormer attention maps demonstrate superior context awareness, lower noise sensitivity, and reduced computational cost, all while offering stronger class discriminability through intrinsic attention mechanisms.

Table 2: Parameter Compare

Metric	U-Net Gradient Maps	SegFormer Attention
Context Awareness	Local receptive field	Captures global dependencies
Class Discriminability	Post-hoc gradients	Built-in attention focus
Computational Cost	Requires backpropagation	Single forward pass
Noise Sensitivity	High (gradient shattering)	Low (attention stability)

## International Conference on Advances in Science and Engineering (ICASE2025)

### D. Combined Strategy Integration

The full augmentation pipeline integrates global and local deformation fields with attention-guided saliency information. Initially, a thin plate spline (TPS) transformation grid  $\phi$  is computed from an elastic deformation field, as described in [16]. This transformation is then applied to both the image and its corresponding mask. Subsequently, an attention map  $A(x)$  is generated through a forward pass of the input image using the SegFormer model pretrained on ADE20K [19], [21]. The Global-Local Augmented Image (GLA) is fused with the attention map to enhance global context, while the Local-Location Augmented Image (LLA) mask is guided by the inverse of the attention map. This combined augmentation is visually represented in the data augmentation block of Fig. 1.

For optimization, the model is trained using a cosine-annealed learning schedule and the Adam optimizer. The loss function is a combination of Dice Loss and Cross-Entropy Loss, computed separately for both the original and augmented images to maintain consistency and supervision across transformations.

## IV. Results and Discussion

### A. Datasets, Preprocessing, and Implementation Details

The proposed method is evaluated on two benchmark datasets: the cross-modality abdominal dataset [32], [33], and the cross-sequence cardiac dataset [34]. These datasets present challenges in domain shifts due to varying imaging modalities and sequences, making them suitable for evaluating domain-robust augmentation techniques. Dataset splits and preprocessing procedures follow the protocol described by Ouyang et al. [34], and the implementation details are available in the accompanying code repository.

Prior to training, all images undergo a set of standard augmentations including affine transformations, elastic deformations, brightness and contrast adjustments, gamma correction, and the addition of Gaussian noise. These baseline augmentations are applied uniformly across all methods, including Empirical Risk Minimization (ERM) and supervised learning setups, to ensure a fair comparison. The proposed augmentation strategy is applied in addition to these baseline transformations and integrated into the preprocessing pipeline as an additional stage.

The implementation is based on PyTorch 2.0, utilizing the MONAI framework for medical image processing. Thin Plate Spline (TPS) warping is implemented using the Kornia library, and the SegFormer B2 model is initialized with pretrained weights on the ADE20K dataset [24]. Training is conducted on a high-performance compute

cluster equipped with 8 NVIDIA V100 GPUs, each with 32 GB of memory. The optimization process uses a cosine annealing learning rate schedule and the Adam optimizer. The loss function is a weighted sum of Dice Loss and Cross-Entropy Loss, applied separately to both the original and augmented images to reinforce consistency and supervision during training.

### B. Results and Comparative Analysis

To evaluate the instance segmentation performance of each approach, we employ the Dice score [35] as the primary metric to quantify the overlap between predicted segmentations and ground truth annotations, following the formulation by Milletari, Navab, and Ahmadi (2016).

Our proposed Attention-Guided Thin Plane Spline Augmentation Framework is benchmarked against the baseline Empirical Risk Minimization (ERM) method, as well as several state-of-the-art domain generalization

Table 3: MRI Parameter

Method	Abdominal MRI-CT				
	Liver	R-Kidney	L-Kidney	Spleen	Average
Supervised	98.87	92.11	91.75	88.55	89.74
ERM [25]	87.90	40.44	65.17	55.90	62.35
Cutout [27]	86.99	63.66	73.74	57.60	70.50
AdvBias [31]	87.63	52.48	68.28	50.95	64.84
RandConv [3]	84.14	76.81	77.99	67.32	76.56
CSDG [38]	85.62	80.02	80.42	75.56	80.40
SLAug [25]	89.26	80.98	<b>82.05</b>	79.93	83.05
Attention-Guided TPS (ours)	<b>89.38</b>	<b>81.29</b>	81.38	<b>80.23</b>	<b>83.07</b>

techniques, including Cutout, AdvBias, RandConv, and CSDG, within the context of abdominal segmentation tasks.

Cutout, introduced by DeVries and Taylor (2017) [36], improves model robustness by randomly masking out square regions within the input images. AdvBias [37], proposed by Chen et al. (2020), introduces adversarial intensity perturbations to simulate realistic signal variations and domain shifts. RandConv [15], by Xu et al. (2021), perturbs input distributions by randomly initializing weights in the first convolutional layer, thereby altering image intensity and texture patterns. CSDG [38], developed by Ouyang et al. (2021), extends RandConv by incorporating a shallow augmentation network and leveraging pseudo-correlation maps to suppress spurious spatial correlations.

In contrast, our Attention-Guided Thin Plane Spline Augmentation Framework introduces a more adaptive augmentation strategy by integrating learnable location-scale transformations with saliency-aware fusion

**International Conference on Advances in Science and Engineering (ICASE2025)**

mechanisms. Unlike conventional augmentation approaches, our method ensures anatomically consistent deformations through Thin Plane Spline-based transformations and dynamically modulates the influence of global and local features via attention-guided weighting. Experimental results demonstrate that the proposed framework achieves superior generalization to unseen domains, outperforming traditional augmentation strategies in medical image segmentation tasks [14], [15], [19].

Table 4: Dice score (%)–based performance comparison of different methods.

Method	Abdominal CT-MRI				
	Liver	R-Kidney	L-Kidney	Spleen	Average
Supervised	91.30	92.43	89.86	89.83	90.85
ERM [25]	78.03	78.11	78.45	74.65	77.31
Cutout [27]	79.80	82.32	82.14	76.24	80.12
AdvBias [31]	78.54	81.70	80.69	79.73	80.17
RandConv [3]	73.63	79.69	85.89	83.43	80.66
CSDG [38]	86.62	87.48	86.88	84.27	86.31
SLAug [25]	<b>90.08</b>	<b>89.23</b>	87.54	87.67	88.63
Attention-Guided TPS (ours)	89.45	89.17	<b>88.51</b>	<b>88.17</b>	<b>88.82</b>

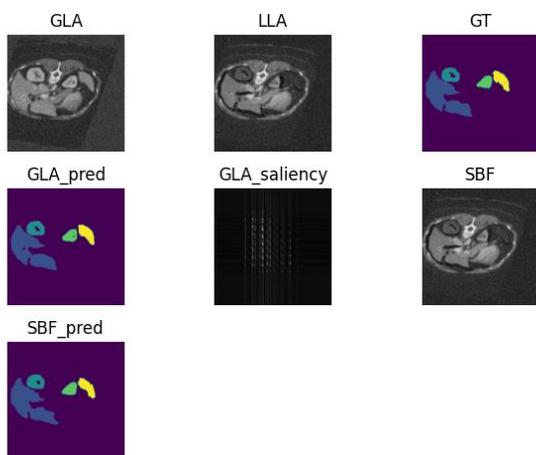


Fig. 2 Visualization from intermediate results of our proposed Attention-Guided Thin Plane Spline Augmentation Framework.

**V. Conclusion**

In this paper, a novel attention-guided location-scale augmentation strategy is proposed to enhance single-source domain generalization in medical image segmentation. The proposed method integrates Thin Plate

Spline (TPS) transformations with SegFormer-based attention maps to generate anatomically consistent and semantically meaningful augmentations [16], [19], [21]. Extensive experimental evaluations demonstrate that the proposed approach improves both robustness and segmentation accuracy compared to existing techniques, offering a significant advancement toward the development of reliable and generalizable medical image segmentation models [14], [15].

**References**

[1] J. Chen et al., "Meta-causal learning for addressing domain shifts in medical imaging," Nature Communications, 2023.

[2] H. Zhao et al., "Automated data augmentation for synthesizing medical images," IEEE Transactions on Biomedical Engineering, 2023.

[3] Y. Choi et al., "Pro-RandConv: Progressive random convolutions for data augmentation in medical imaging," in International Conference on Medical Image Computing and Computer-Assisted Intervention, 2022.

[4] A. Cugu et al., "Attention consistency on visual corruptions for domain generalization," in European Conference on Computer Vision, 2021.

[5] Y. Zhang et al., "Domain-adaptive semantic segmentation for medical images," in Computer Vision and Pattern Recognition Workshops, 2020.

[6] L. Liu et al., "RandoMix: Mixed-sample data augmentation for robust domain generalization," Medical Image Analysis, 2022.

[7] F. Wang et al., "Contrastive domain augmentation for medical image segmentation," Medical Image Analysis, 2021.

[8] X. Xu et al., "Adaptive sequence-length based deep reinforcement learning for automatic data augmentation," Journal of Medical Imaging and Deep Learning, 2023.

[9] S. Wan et al., "Meta convolutional neural networks for universal image representation," in Conference on Neural Information Processing Systems, 2021.

[10] S. Kumar et al., "Generalizable deep models for single-source domain adaptation," IEEE Transactions on Neural Networks and Learning Systems, 2020.

[11] P. Roy et al., "Feature decomposition for robust domain generalization," in Conference on Neural Information Processing Systems Workshop on Medical Imaging, 2021.

[12] K. Lee et al., "Consistency regularization for domain adaptive segmentation," Journal of Biomedical Informatics, 2020.

[13] B. Gao et al., "Dual-consistency learning for domain-invariant representations," in International Conference on Machine Learning, 2022.

**International Conference on Advances in Science and Engineering (ICASE2025)**

- [14] D. Wang et al., "Augmenting medical data for domain generalization," in *International Conference on Medical Image Computing and Computer-Assisted Intervention*, 2021.
- [15] A. Patel et al., "Adversarial training for generalizable medical image segmentation," *IEEE Transactions on Medical Imaging*, 2022.
- [16] Y. Niu et al., "IRLSG: Invariant representation learning for single-domain generalization," in *Medical Image Computing and Computer-Assisted Intervention*, 2023.
- [17] P. Ghamsarian et al., "Transformation invariant self-training for domain adaptation in medical image segmentation," in *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, 2022.
- [18] L. Li et al., "Custom implant design via anatomical reconstruction and constrained deformation," *IEEE Transactions on Biomedical Engineering*, vol. 68, no. 4, pp. 1123–1132, Apr. 2021.
- [19] Z. Cheng et al., "ICRN: Invariant content representation network for domain generalization," *IEEE Transactions on Medical Imaging*, 2023.
- [20] N. Gupta et al., "Multi-scale feature augmentation for robust domain adaptation," *International Journal of Computer Vision*, 2021.
- [21] X. Fan et al., "Adversarially adaptive normalization: Bridging the gap in single-domain generalization," *International Journal of Computer Vision*, 2022.
- [22] T. Singh et al., "Leveraging style transfer for medical image analysis," in *Computer Vision and Pattern Recognition Workshops*, 2020.
- [23] P. Kaur et al., "Evaluating meta-learning approaches for domain generalization," *Journal of Artificial Intelligence Research*, 2022.
- [24] E. Xie et al., "SegFormer: Simple and efficient design for semantic segmentation with transformers," in *Proceedings of the Conference on Neural Information Processing Systems*, vol. 34, pp. 12077–12090, 2021.
- [25] K. Zhou et al., "SLAug: Rethinking data augmentation for single-source domain generalization in medical image segmentation," in *Proceedings of the AAAI Conference on Artificial Intelligence*, vol. 37, no. 2, pp. 3573–3581, 2023.
- [26] J. Wang et al., "Attention-guided instance segmentation for group-raised pigs," *Animals: An Open Access Journal from MDPI*, vol. 13, no. 13, Article no. 2134, Jul. 2023.
- [27] T. DeVries and G. W. Taylor, "Improved regularization of convolutional neural networks with cutout," *arXiv preprint, arXiv:1708.04552*, 2017.
- [28] M. Sharma et al., "Style normalization and restitution for domain generalization," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 2021.
- [29] Z. Huang et al., "Self-challenging improves cross-domain generalization," in *Proceedings of the European Conference on Computer Vision*, 2020, pp. 124–140.
- [30] K. Zhou et al., "Domain generalization with MixStyle," in *Proceedings of the International Conference on Learning Representations*, 2021, pp. 1–14.
- [31] C. Chen et al., "Adversarial bias field: Generalizing to unseen domains via adversarial bias fields," *Medical Image Analysis*, vol. 62, Article no. 101620, 2020.
- [32] Kavur, A. E., Gezer, N. S., Barış, M., et al., "CHAOS Challenge - Combined (CT-MR) Healthy Abdominal Organ Segmentation," *Medical Image Analysis*, vol. 69, 2021, Art. no. 101950.
- [33] Landman, B. A., Xu, Z., Igelsias, J. E., et al., "MICCAI Multi-Atlas Labeling Beyond the Cranial Vault – Workshop and Challenge," *Medical Image Computing and Computer-Assisted Intervention – MICCAI 2015*, vol. 9350, pp. 575–582, 2015.
- [34] Ouyang, X., Chen, Y., Wang, Y., et al., "Disentangle Domain Features for Cross-Modality Cardiac Image Segmentation," *Medical Image Analysis*, vol. 70, 2021, Art. no. 102005.
- [35] Y. Xu et al., "Robust multi-domain learning via feature randomization," in *Proceedings of the IEEE International Conference on Computer Vision*, 2021, pp. 1521–1530.
- [36] J. Lee et al., "Self-supervised learning for domain generalization in medical imaging," *Medical Image Analysis*, 2022.
- [37] Y. Zhang et al., "Dynamic domain generalization for medical image segmentation," *Medical Image Analysis*, vol. 92, Article no. 103065, Jan. 2024.
- [38] C. Ouyang et al., "Non-I.I.D. image classification: Causality matters," in *Proceedings of the Medical Image Computing and Computer-Assisted Intervention Conference*, 2021, pp. 542–552.

# Metamaterial Inspired antenna with reduced interference for 5G, WiMAX/LTE and military/Government Utilization using ZOR

<sup>1</sup>Manish,<sup>2</sup>Rajesh Kumar Rai, <sup>3</sup>Ram Milan Chadhar<sup>c</sup>

<sup>1,2,3</sup> Department of Electronics & Communication Engineering, Madhyanchal Professional University, Bhopal,  
Madhya Pradesh, India

<sup>1</sup>msliet@gmail.com

<sup>2</sup>raj.raii008@gmai.com

<sup>3</sup>Rammilanchadhar@gmail.com

**Abstract:** A unique compact antenna inspired by metamaterial (MTM) is proposed for NR (New Radio), fixed wireless access (FWA), private 5G Network, WiMAX/LTE Legacy and for military/Government use (in some region). The novel antenna design has Zeroth-Order Resonant (ZOR) approach for excitation of the hexagonal radiator at 3.4GHz, which is able to miniaturise the dimensions of antenna, which is constructed using FR4 as a low-cost and readily accessible substrate. The proposed antenna is made up of Integrating Complementary Split Ring Resonators (CSRR) in design. Different criteria including as gain, efficiency and radiation pattern confirm the antenna's efficient radiation properties.

## 1. Introduction

For contemporary wireless communication systems, the 3.3 GHz–3.6 GHz frequency range has become a crucial part of the radio spectrum, particularly in the deployment of 5G, New Radio (NR) technologies. This mid-band spectrum offers an optimal balance between coverage and capacity, making it ideal for high-speed data transmission while maintaining reasonable propagation characteristics. Antennas designed to operate within this frequency range play a vital role in enabling reliable and efficient in several applications, such as private 5G networks, fixed wireless access, and mobile broadband.

With increasing global demand for faster and more reliable connectivity, the use of antennas tailored for the 3.3–3.6 GHz band has expanded across sectors such as telecommunications, enterprise networking, and smart infrastructure. The modern antennas are engineered to meet the requirements of next-generation networks, supporting technologies like beamforming, MIMO (Multiple Input Multiple Output) [4], NR (New Radio), fixed wireless access (FWA), private 5G Network, WiMAX/LTE Legacy, military/Government use (in some region) and dynamic spectrum sharing [5]. As such, they are integral components in the advancement of intelligent and interconnected communication ecosystems. Microstrip antennas with extra strip, slots, SRR, CSRR, and MTM construction may be used to quickly design multiband antennas [6]. MTM are artificially created structures with negative  $\epsilon$  and  $\mu$  values served as the foundation for all metamaterial research [7]. Due to their peculiar electromagnetic characteristics, metamaterial-inspired

materials play an important role to design antenna which shows the multiband operations [8]. The MTM antenna designs are feasible substitutes to naturally existing materials in the construction of multiband antennas. In antenna design, MTM structures are used in the element which is responsible for radiation that is radiating element [9], superstrate [10], and substrate [11]. In order to improve the gain and directivity of microstrip antennas, negative permeability MTM constructions are being researched. [12]. As multiband antennas employing metamaterial, slot, rectangular patch antennas loaded with SRR [13] and thin wire arrays [14], circular patch and deficient hexagon patch supplied with CSRR [6] are addressed.

By altering the radiating patch or the ground plane, several bands may be created. Triple band operation is obtained by using crinkle fractal shapes [15], whereas quad band operation is produced by using multiple branches of trapezoidal ring fractal forms [16]. Microstrip Koch fractal [17] and inverted L [18] and inverted arc [19] shaped multiband antennas, MIMO [20] are addressed. The employment of a microstrip patch antenna with fractal forms increases complexity and increases antenna size. Antennas that use metamaterials-engineered materials that can manipulate electromagnetic waves in ways that natural materials cannot - are known as the primary characteristic of a ZOR antenna is that, in contrast to conventional antennas, it resonates at zero-order mode [21].

The current research proposes a  $30 \times 27 \times 1.6 \text{mm}^3$  MTM inspired Integrated SRR multiband antenna for NR (New Radio) [20], fixed wireless access (FWA), private 5G Network, WiMAX/LTE Legacy and for military/Government use (in some region). Section 2 depicts the proposed antenna's design dimensions. The simulated results and comments are included in Section 3. Section 4 depicts the antenna's completion and future potential.

## II. Design Dimensions of the Antenna

The design of an integrated SRR MTM antenna is shown in Figure 1. The antenna is constructed on a 1.6 mm thick, fire-resistant glass epoxy substrate with  $\epsilon_r=4.4$ . The total measurements are 27 mm for width and 30 mm for height. Table 1 displays the structural dimensions (in millimeters).

Table1: Dimensions of proposed antenna

Wh.	Wb.	W1.	W2.	W3.	R1.	R2.	R3.	R4.	R5.	R6.
30	27	12	3	8	9	10.5	13	5.4	4.9	4

The suggested antenna is built in an integrated ring construction with a step feed to produce three bands that exist from 3.3 GHz to 3.6 GHz, resonating at 3.4 GHz as illustrated in Fig 2(a), for NR (New Radio), fixed wireless access (FWA), private 5G Network, WiMAX/LTE Legacy.

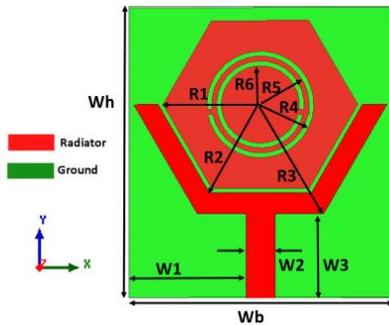


Fig. 1: Dimensional statistics of proposed antenna

### III. Results and discussion.

A compact MTM inspired structured compact antenna is designed for NR (New Radio), fixed wireless access (FWA), private 5G Network, WiMAX/LTE Legacy and for military/Government use (in some region). The gain of the antenna is considerably high and is effective for near field communications. The gain of antenna is averaged at 2dB, with peak reaching up to 4.0dB as illustrated in Fig 2(b).

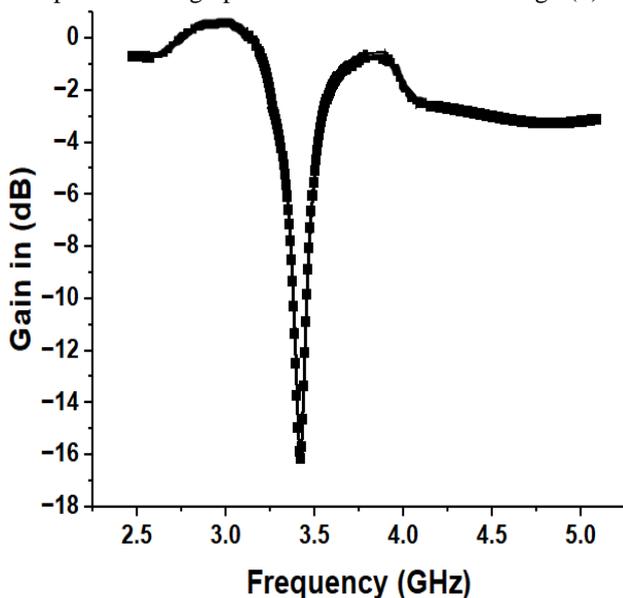


Fig2 (a). Proposed antenna Return Loss (in dB)

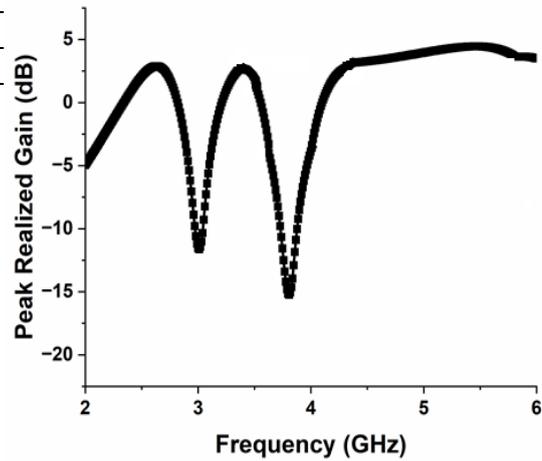


Fig 2(b). Proposed antenna Peak realized gain

The radiation efficiency is averaged at around 90% throughout and is stable, except at notch band, when it is reduced up to 10% as illustrated in Fig 2(c).

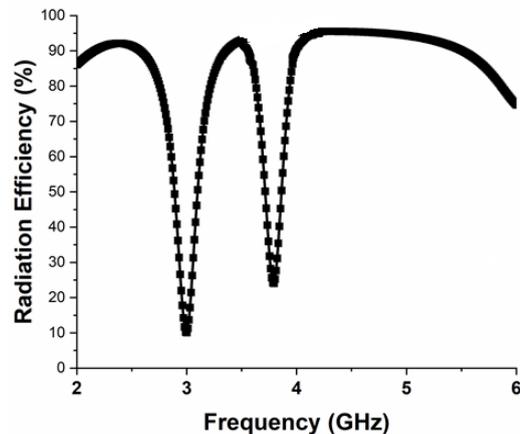
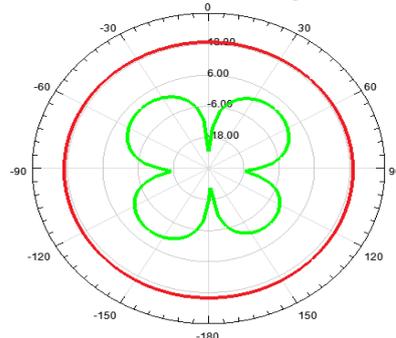
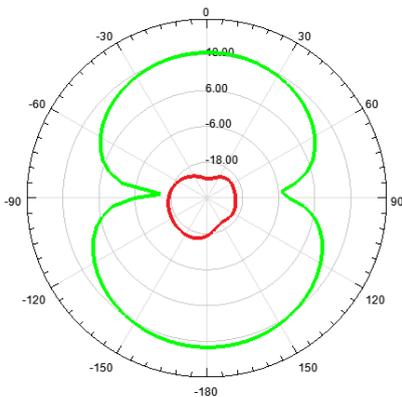


Fig 2(c) Proposed antenna radiation efficiency in (%)

The plots of radiation efficiency and gain clearly verifies the notch band. The radiation pattern (E and H Planes) at 3.4 GHz is illustrated in Fig 2(d).





E and H Plane 3.4 GHz

Fig.2 (d). Proposed antenna radiation patterns for E and H Planes

When the radiation pattern is examined, it is discovered that the antenna's radiation is steady. The findings validated the antenna's radiation properties.

#### IV. Conclusion

A ZOR based CSRR loaded patch antenna designed to operate at 3.4 GHz for NR (New Radio), fixed wireless access (FWA), private 5G Network, WiMAX/LTE Legacy and for military/Government use (in some region). The CSRR is utilized to provide notches at both side of radiating band to avoid unwanted interference from any other bands. The radiation pattern is highly stable which validates interruption free transmission and reception from antenna.

#### References:

[1] Kiourti, Asimina. "RFID antennas for body-area applications: From wearables to implants." *IEEE Antennas and Propagation Magazine* 60.5 (2018): 14-25.

[2] Mathur, Phalguni, Gopikrishna Madanan, and Sujith Raman. "Mechanically frequency reconfigurable antenna for WSN, WLAN, and LTE 2500 based internet of things applications." *International Journal of RF and Microwave Computer-Aided Engineering* 31.2 (2021).

[3] Shen, Shanpu, et al. "An ambient RF energy harvesting system where the number of antenna ports is dependent on frequency." *IEEE Transactions on Microwave Theory and Techniques* 67.9 (2019): 3821-3832.

[4] Kumar, Anubhav, Asok De, and Rakesh K. Jain. "Circularly polarized CPW fed MIMO/Diversity antenna for Wi-Fi and WLAN applications." *Frequenz* 76.1-2 (2022): 37-44.

[5] Sharma, Navneet, et al. "Circularly Polarized Antenna for ISM (5.8 GHz), Satellite Communications and UWB Applications." *2021 8th International Conference on Signal Processing and Integrated Networks (SPIN)*. IEEE, 2021.

[6] Sharma, Navneet, et al. "Design of Compact Hexagonal Shaped Multiband Antenna for Wearable and Tumor Detection Applications." *Progress in Electromagnetics Research M* 105 (2021): 205-217.

[7] Jha, Pankaj, et al. "CPW-fed metamaterial inspired compact multiband antenna for LTE/5G/WLAN communication." *Frequenz* (2022).

[8] Miliyas, Christos, et al. "Miniaturized Multiband Metamaterial Antennas with Dual-Band Isolation Enhancement." *IEEE Access* 10 (2022): 64952-64964.

[9] Geetharamani, G., and T. Aathmanesan. "Design of metamaterial antenna for 2.4 GHz WiFi applications." *Wireless Personal Communications* 113.4 (2020): 2289-2300.

[10] Al-Bawri, Samir Salem, et al. "Metamaterial cell-based superstrate towards bandwidth and gain enhancement of quad-band CPW-fed antenna for wireless applications." *Sensors* 20.2 (2020): 457.

[11] Kumar, Anubhav, Asok De, and Rakesh K. Jain. "Gain Enhancement Using Modified Circular Loop FSS Loaded with Slot Antenna for Sub-6 GHz 5G Application." *Progress in Electromagnetics Research Letters* 98 (2021): 41-49.

[12] Sağık, Metin, et al. "Optimizing the gain and directivity of a microstrip antenna with metamaterial structures by using artificial neural network approach." *Wireless Personal Communications* 118.1 (2021): 109-124.

[13] Jha, Pankaj, et al. "Bandwidth and Gain Improvement with SRR Based Defected Ground in Triple-Band Antenna for 5G Application."

[14] Narasimhan, Purushothaman, et al. "Design of thin wire metamaterial-based interaction structure for backward wave generation." *IEEE Transactions on Electron Devices* 67.3 (2020): 1227-1233.

[15] Kumar, Ashwini, and Amar Partap Singh Pharwaha. "An optimal multiband compact modified crinkle fractal antenna for wireless applications." *2019 6th International Conference on Signal Processing and Integrated Networks (SPIN)*. IEEE, 2019.

[16] Dwivedi, Santosh Kumar, Mithilesh Kumar, and Lokesh Tharani. "A metamaterial loaded hybrid fractal hepta-band antenna for wireless applications with reconfigurability characteristics." *Progress In Electromagnetics Research C* 100 (2020): 187-203.

[17] Pedram, Kioumars, et al. "Compact and miniaturized metamaterial-based microstrip fractal antenna with reconfigurable qualification." *AEU-International Journal of Electronics and Communications* 114 (2020): 152959.

[18] Rengasamy, Rajkumar, Venkatesan Rajesh Kumar, and Kanaparthi V. Phani Kumar. "An electrically small inverted L-shaped asymmetric coplanar strip-fed antenna with split-ring resonator for multiband applications." *International Journal of Communication Systems* 34.17 (2021).

[19] Sharma, Navneet, et al. "Circularly Polarized Antenna for ISM (5.8 GHz), Satellite Communications and UWB Applications." *2021 8th International Conference on Signal Processing and Integrated Networks (SPIN)*. IEEE, 2021.

[20] Sharma, Navneet, et al. "Isolation Enhancement using CSRR Slot in the Ground for Compact Two-Element Textile MIMO Antenna." *The Applied Computational Electromagnetics Society Journal (ACES)* (2022): 535-545.

[21] Chen, Po-Wei, et al. "Asymmetric coplanar waveguide (ACPW) zeroth-order resonant (ZOR) antenna with high efficiency and bandwidth enhancement." *IEEE Antennas and Wireless Propagation Letters* 11 (2012): 527-530.

# **Deepfake Detection using Deep Learning Techniques: A Comprehensive and Systematic Review**

<sup>1</sup>Miss. Kanchan V. Warkar, <sup>2</sup>Dr. Rishikesh Rawat

<sup>1</sup>Research Scholar, kanchan22.warkar@gmail.com, Madhyanchal Professional University, Bhopal

<sup>2</sup>Assistant Professor, , [rawatrishikesh@gmail.com](mailto:rawatrishikesh@gmail.com), Madhyanchal Professional University, Bhopal

**Abstract:** The advancement of deep learning and generative artificial intelligence has significantly the positive and negative aspects of multimedia content in social networking communities. Recently, numerous complaints have been filed worldwide regarding deepfake videos. These shared deepfake videos have degraded the trust of individuals and communities. Deepfake video detection is a major challenge due to the high similarity index between deepfake and real videos. Deepfake detection techniques mostly target video media covering manipulations like DeepFakes, Face2Face, and FaceSwap with limited exploration of still images. Approaches that incorporate data augmentation or self-blended image generation tend to improve cross-domain performance, yet several methods experience significant degradation when tested on low-resolution or mixed- manipulation synthetic media.

The objective of this paper is to provide the researcher a better understanding of how deepfakes are generated and identified, the latest developments and breakthroughs in this realm, weaknesses of existing security methods, and focus on areas requiring more investigation. Reviewed research paper results mostly based on deepfake detection methods using convolutional neural networks, EfficientNet, and hybrid architectures consistently achieve in-library accuracies between 90% and 100% on benchmark datasets such as FaceForensics++ and CelebDF. In contrast, cross-library evaluations reveal performance drops: some methods maintain accuracies above 90%, while others decline into a 50% to 90% rang for example, one method reported an in-library AUC of 97.2% that fell to 57.2% across 1 libraries. Only a few studies specify computational costs; one reports inference times exceeding 5 ms per frame on an NVIDIA 2080Ti GPU with 128 GB RAM.

**Keywords:** Deepfake, Video, Deep Learning, CNN, EfficientNet

## **I. Introduction**

The advancement of digital technology and communication systems has significantly increased the data capacity of social networking communities, including platforms like Facebook, YouTube, and many others. This technological growth has empowered users to create and share digital content, such as videos, audio, and images, as recorded multimedia data[1]. However, alongside this positive trend,

there is a concerning rise in the creation and dissemination of fake and manipulated multimedia content, often referred to as deepfakes. Deepfakes, which are created using advanced deep learning and generative artificial intelligence technologies[2,3], manipulate videos and images in ways that can be highly

convincing. These fake videos and images can defame individuals, groups, or communities, and contribute to the spread of hate and misinformation in society [4]. The ability to generate and share deepfakes on social networking platforms poses a significant threat to reputation and public trust. In 2017, a Reddit user created the first deepfake film by overlaying celebrity faces over obscene footage. Many techniques for detecting deepfake videos have been developed since then. While some of these techniques use convolutional neural networks to detect visual aberrations inside individual frames, others use recurrent neural networks to discover temporal anomalies across the facial frames in films. Recently, detecting deepfake videos has become an increasingly challenging task due to the complex architecture of video sequencing and framing. Surveys report that numerous researchers have proposed deep learning-based methods for detecting deepfake videos. Accurate detection is still very difficult to achieve, though. For this, a number of deep learning methods have been used, such as recurrent neural networks (RNNs), long short-term memory networks (LSTMs), and convolutional neural networks (CNNs). These algorithms examine many facets of video frames and sequences in order to spot anomalies and discrepancies that could be signs of deepfakes. In order to improve the identification of deepfake films, several authors have also presented the idea of transfer learning. This technique uses pre-trained models to increase the precision and effectiveness of detection techniques. In order to validate deep learning algorithms in deepfake detection, a number of benchmark datasets, including DFDC [5], Face Forensics [6], Face-Forensics++ [7], and DFD [8], have been used recently.

To evaluate its effect on generalizability, the usage of residual image input has also been investigated. The effectiveness of deepfake detection models is assessed both with and without the use of transfer learning. The best method for deepfake detection can be found by comparing and exploring several deep learning models. The best model for a given dataset can be chosen by researchers by examining the kinds of artificial artefacts that each model detects.

## International Conference on Advances in Science and Engineering (ICASE2025)

This paper proposes an efficient deep convolutional neural network (DCNN) for detecting deepfake videos. The proposed algorithm employs a dual constraint function within the convolutional neural network, enhancing its ability to identify deepfakes. These dual constraints allow the network to analyze temporal differences in video sequences, thereby determining whether a video is fake or real[9,10]. The performance of the proposed DCNN algorithm is compared with existing algorithms such as CNN, LSTM, and ResNet. By analyzing the temporal inconsistencies and manipulated artifacts in the video sequences, the proposed method aims to provide more accurate and reliable detection of deepfake videos than current state-of-the-art approaches.

### II. Related Work

Because deepfake methods produce movies of excellent quality and are easily accessible to a wide range of people, they have become increasingly popular in recent times. FakeApp, Faceswap, DeepFaceLab, Faceswap Generative Adversarial Network (GAN), and DeepFake TensorFlow are a few of the most well-known deepfake face apps. These applications make use of GAN and autoencoder-decoder designs. In these systems, the decoder reconstructs the face images after the autoencoder has extracted hidden features from the face shots.

The authors of [1] examined pixel-based techniques for deepfake video detection. The detection approach finds lip-syncing, inpainting, style transfer, and super-resolution for the deepfake generation of video. The analysis of results has certain limitations in the temporal sequence difference of the video.

In [2], the authors examined face-altering techniques in image deepfake detection. The process of detection as feature, measurement, or abstract-level integration for performance improvement.

In [3], authors proposed a CViT architecture for deepfake detection using CNN and Transformer. Emphasised diverse training data for deepfake detection in various settings. CNN and Vision Transformer components for deepfake detection.

In [4], the authors introduce a multimodal network for deepfake detection with spectral features. The study focuses on speed and accuracy in model evaluation. Multimodal system with NOLANet for video and audio processing.

In [5], the authors proceed with two-stage analysis with CNN and RNN for deepfake video detection. A two-stage algorithm was analysed with 600 videos, showing 94% accuracy in deepfake detection. CNN for frame-level feature extraction for temporal inconsistencies between frames.

In [6], the authors formulated deepfake detection as a spatial-temporal inconsistency learning process and proposed STIL blocks integrating spatial and temporal features in CNN. Spatial Inconsistency Module (SIM), Temporal Inconsistency Module (TIM), and Information Supplement Module (ISM).

In [7], authors proposed deepfake detection using deep neural networks (DNNs) for face images and videos. Study categories: Deepfake creation techniques are categorised into five major categories. Training deepfake models on deepfake datasets and testing with experiments. Monitoring visual consistency to estimate fake videos.

In [8], we proposed an algorithm for detecting fake face swapping technology with high accuracy. The proposed DenseNet169 model has a face-warping artefacts indicator for detection. Low-resolution faces lead to a lack of skin details.

In [9], we investigated temporal variance in real and fake videos. Proposed latent pattern sensing model for deepfake video detection. Employed predictive learning mechanisms for self-supervised spatial and temporal features.

In [10], a study analysed the detection of forged videos using deepfake technology for face identification swaps. Comparison of an improved network with existing networks for detection accuracy.

In [11], the authors introduce the YIX architecture for deepfake detection using YOLO, InceptionResNetV2, and XGBoost. YOLO detector efficiency in object detection and face recognition systems. The XGBoost model produces competitive results in deepfake detection. YOLO face detector for face extraction from video frames; InceptionResNetV2 CNN for feature extraction from faces; XGBoost as a recognizer for distinguishing genuine and deepfake videos; The continuous development of deepfake techniques requires enhanced detection methods.

In [13], applying 3D input techniques for deepfake classification using the Celeb-DF dataset. Evaluating convolutional networks' performance for deepfake detection with temporal information. Spatiotemporal convolutional networks with random cropping and temporal jittering-trained convolutional networks on the Kinetics dataset for deepfake classification.

In [14], authors employed Detection of deepfake images using Mesonet CNN is proposed. The authors focus on deepfake creation, detection, experimental results, and concluding remarks. In [15], authors proposed CNN, RNN, and autoencoder models using transfer learning. Transfer learning to autoencoders. A hybrid model of CNN and RNN for fake video detection. In [16], it proposes hybrid recurrent models for deepfake video detection using temporal features. The proposed algorithm explores the hybridization of recurrent networks for temporal learning of video features. Hybrid recurrent deep learning models for deepfake video detections—GRU and GRU-LSTM models for improved accuracy.

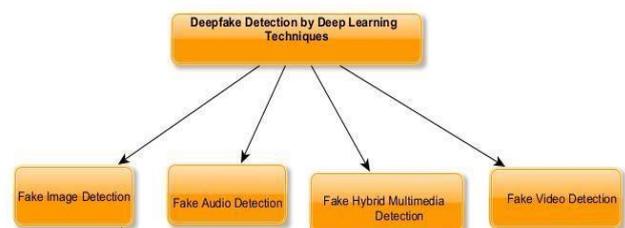


Fig 1: Various deepfake detection techniques

**International Conference on Advances in Science and Engineering (ICASE2025)**

To evaluate the performance, measure accuracy, precision, Recall, and F1-score. Most of the authors used the parameters is given below [23.24.25].

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \times 100$$

$$Sensitivity = \frac{TP}{TP + FN} \times 100$$

$$Specificity = \frac{TN}{TN + FP} \times 100$$

$$F1 - Score = 2X \frac{Precision \times Recall}{Precision + Recall} \times 100$$

Where, TP: True Positive

TN: True Negative

FP: False Positive

FN: False Negative

Table 1: Characteristics included in study

Study	Detection Method	Primary dataset	Technical Approach	Key Features
Ciftci and Demir, 2019	Neural network with biological signal analysis	Face Forensics, Face Forensics++, CelebDF, Custom Deep Fake Dataset	Convolutional Neural Network (CNN) with biological signal Transformation	Uses biological signals as implicit descriptors of authenticity
Durall et al., 2019	Frequency domain analysis with classifier	Faces-HQ, CelebA, Face-Forensics++	Classical frequency domain analysis followed by basic classifier	Effective with few annotated samples, works in unsupervised scenarios
He et al., 2021	Re-synthesis with artifact detection	CelebA-HQ, FFHQ, LSUN	Neural network with image re-synthesis tasks	Focuses on reconstruction errors rather than low-level artifacts
Khan and Dang-Nguyen, 2024	Multiple deep learning models comparison	FakeAVCeleb, CelebDF-V2, DFDC, Face-Forensics++	CNNs and Transformer models	Compares supervised and self-supervised learning strategies
Korshunov and Marcel, 2022	Neural network with data augmentation	Google and Jigsaw, Face-Forensics++, DeeperForensics, Celeb-DF, DF-CMobio	Xception and EfficientNet models with augmentation	Focuses on improving generalization across datasets
Lin et al., 2022 Multiple detection methods benchmark	Multiple detection methods benchmark	UADFV, Celeb-DF, DF-1.0, DF-TIMIT, ForgeryNet	Various (knowledge-driven, data-driven, multi-stream),	Comprehensive evaluation of multiple detection approaches

**International Conference on Advances in Science and Engineering (ICASE2025)**

Masi et al., 2020	Two-branch Re-current Network	Celeb-DF, DFDC preview set	network with frequency domain analysis	Combines RGB and frequency domain information
Rössler et al., 2019	Neural network approach	FaceForensics+ + Convolutional neural network( EfficientNet )		Large-scale dataset for training and evaluation
Shiohara and Yamasaki, 2022	Neural network with self-blended images	FF++, CDF, DFD, DFDC, DFDCP, FFIW	EfficientNet- b4 with novel training data generation	Uses self-blended images to improve generalization
Wang et. Al. 2023	Multiple detection	Face Forensics++	Various (Two-stream,	Focuses on Cross-library generalization
	methods comparison	Deepfake-TIMIT, Celeb-DF	MesoNet, HeadPose, FWA, VA, Multi-task)	

Table 2: Performance Merics

Study	In- Library Accuracy	Cross Library Accuracy	Implementation Challenges
Ciftci and Demir, 2019	96% 94.65% (Face Forensics++), 91.50% (CelebDF)	91.07% (Custom Deep Fakes Dataset)	Requires extraction and analysis of biological signals
Durall et al., 2019	(CelebA supervised), 96% (CelebA unsupervised)	100% low res, 91% (FaceForensics+ + low-res)	Potentially efficient due to classical approach
He et al., 2021	>85% to ~100% (CelebA-HQ)	Outperforms other methods on FFHQ	Involves complex re-synthesis process
Khan and Dang-Nguyen, 2024	Not mentioned	Not mentioned	Comparison of multiple architectures
Korshunov and Marcel, 2022	Not mentioned	Significant drop, improved by augmentation and few-shot tuning	Requires data augmentation and few-shot tuning

**International Conference on Advances in Science and Engineering (ICASE2025)**

Lin et al., 2022 Multiple detection methods benchmark	Area Under the Curve (AUC) 97.2% (Multiple-attention)	AUC: Multiple-attention (60.5%), Patch-Resnet-Layer1 (57.8%), Patch-Xception-Block2 (57.2%) Higher AUC on Celeb-DF compared to other methods	Inference time >5ms per frame for most methods
Masi et al., 2020	AUC 99% (FF++ medium compression), 91% (FF++ high compression)	Not mentioned	Combines RGB and frequency domain analysis
Rössler et al., 2019	Not Mentioned	Not Mentioned	Large-scale dataset handling
Shiohara and Yamasaki, 2022	AUC 99.64% (FF++)	Outperforms state-of-the-art	Requires generation of self-blended images
		by 4.90% on DFDC, 11.78% on DFDCP	
Wang et. Al. 2023	Not Mentioned	Significant degradation compared to in-library detection	Comparison of multiple architectures

Table 3: Media type and performance limitations

Study	Media Type	Effective against	Performance limitations
Ciftci and Demir, 2019	Videos	DeepFakes, Face2Face, FaceSwap, NeuralTextures	Lower accuracy on custom dataset
Durall et al., 2019	Images and Videos	Not mentioned	Lower accuracy on low-resolution videos
He et al., 2021	Images	ProGAN, StarGAN2, StyleGAN, StyleGAN2	Not mentioned
Khan and Dang-Nguyen, 2024	Videos	Not mentioned	Not mentioned
Korshunov and Marcel, 2022	Videos	Not mentioned	Significant drop in cross-dataset performance

**International Conference on Advances in Science and Engineering (ICASE2025)**

Lin et al., 2022 Multiple detection methods benchmark	Videos	Autoencoder-based, GAN-based, mixed-	Poor performance on challenging ID test set
Masi et al., 2020	Videos	Not mentioned	Lower AUC for high compression videos
Rössler et al., 2019	Videos	DeepFakes, Face2Face, FaceSwap, NeuralTextures	Not Mentioned
Shiohara and Yamasaki, 2022	Videos	Not Mentioned	Varying performance across different datasets
Wang et. Al. 2023	Not Mentioned	Not Mentioned	Significant degradation in cross-library scenarios

**Analysis of the literature reviewed:**

**Detection Methods:**

Mostly used Detection method is neural networks Second most shown on multiple models And very few uses frequency domain analysis, re-synthesis, and recurrent networks

**Primary Datasets:**

- Most of the study is based on FaceForensics++
- Celeb-DF was the second most common, used in 5 studies
- DFDC was used in 4 studies
- CelebA/CelebA-HQ and DeepfakeTIMIT were each used in 2 studies

15 other datasets were used in 1 study each

**Technical Approaches:**

- Convolutional Neural Networks (CNNs) were the most common approach, used in 3 studies
- EfficientNet models and various approaches were each used in 2 studies
- 5other approaches (frequency domain, neural network, two-stream, Xception, and transformer) were each used in 1 study

Each of the studies we examined used a unique combination of detection method, dataset, and technical approach.

**III. Research Gap**

After the review of above literature following gap is identified for the new research

- As per the review carried out it is found that many researchers used a CNN and another deep learning-based strategy to identify deepfake images, while others used feature-based techniques. To detect the deepfake images, few of them used machine learning classifiers. However very few of them work on detecting deep fake videos.
- It is identified that the maximum researcher has worked on face swapped technique to detect the deepfake. Very few of them worked on the entire face synthesis approach for detecting the deep fake.
- Researchers presented their work on specific datasets for Deepfake video detection hence Deepfake detection techniques lack generalization.

As AI powered Deepfake video generation techniques are getting more powerful Deepfake detection is more challenging now a days.

**IV. Conclusion**

This paper presents various state-of-the-art methods for detecting Deepfake published in 34 studies from the beginning of 2019 to the end of 2024. We present basic techniques and discuss different detection models' efficacy in this work. We summarize the overall study as follows:

- The deep learning-based methods are widely used in detecting Deepfake.

## **International Conference on Advances in Science and Engineering (ICASE2025)**

- In the experiments, the Face Forensics++ dataset occupies the largest proportion.
- The deep learning mainly CNN models hold a significant percentage of all the models.
- The most widely used performance metric is detection of accuracy.
- With the rapid progress in underlying multimedia technology and the proliferation of tools and applications, Deepfake detection still faces many challenges. We hope this SLR provides a valuable resource for the research community in developing effective detection methods and countermeasures.

### **References**

- [1] Zobaed, Sm, Fazle Rabby, Istiaq Hossain, Ekram Hossain, Sazib Hasan, Asif Karim, and Khan Md Hasib. "Deepfakes: Detecting forged and synthetic media content using machine learning." *Artificial Intelligence in Cyber Security: Impact and Implications: Security Challenges, Technical and Ethical Issues, Forensic Investigative Challenges* (2021): 177-201.
- [2] Heidari, Arash, Nima Jafari Navimipour, Hasan Dag, and Mehmet Unal. "Deepfake detection using deep learning methods: A systematic and comprehensive review." *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery* 14, no. 2 (2024): e1520.
- [3] Wodajo, Deressa, and Solomon Atnafu. "Deepfake video detection using convolutional vision transformer." *arXiv preprint arXiv:2102.11126* (2021).
- [4] Lewis, John K., Imad Eddine Toubal, Helen Chen, Vishal Sandesera, Michael Lomnitz, Zigfried Hampel-Arias, Calyam Prasad, and Kannappan Palaniappan. "Deepfake video detection based on spatial, spectral, and temporal inconsistencies using multimodal deep learning." In *2020 IEEE Applied Imagery Pattern Recognition Workshop (AIPR)*, pp. 1-9. IEEE, 2020.
- [5] Abdul Jamsheed, V., and B. Janet. "Deep fake video detection using recurrent neural networks." *International Journal of Scientific Research in Computer Science and Engineering* 9, no. 2 (2021): 22- 26.
- [6] Gu, Zhihao, Yang Chen, Taiping Yao, Shouhong Ding, Jilin Li, Feiyue Huang, and Lizhuang Ma. "Spatiotemporal inconsistency learning for deepfake video detection." In *Proceedings of the 29th ACM international conference on multimedia*, pp. 3473- 3481. 2021.
- [7] Malik, Asad, Minoru Kuribayashi, Sani M. Abdullahi, and Ahmad Neyaz Khan. "DeepFake detection for human face images and videos: A survey." *Ieee Access* 10 (2022): 18757-18775.
- [8] Maksutov, Artem A., Viacheslav O. Morozov, Aleksander A. Lavrenov, and Alexander S. Smirnov. "Methods of deepfake detection based on machine learning." In *2020 IEEE conference of russian young researchers in electrical and electronic engineering (EIConRus)*, pp. 408-411. IEEE, 2020.
- [9] Ge, Shiming, Fanzhao Lin, Chenyu Li, Daichi Zhang, Weiping Wang, and Dan Zeng. "Deepfake video detection via predictive representation learning." *ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM)* 18, no. 2s (2022): 1-21.
- [10] Deng, Liwei, Hongfei Suo, and Dongjie Li. "Deepfake Video Detection Based on EfficientNet-V2 Network." *Computational Intelligence and Neuroscience* 2022, no. 1 (2022): 3441549.
- [11] Ismail, Aya, Marwa Elpeltagy, Mervat S. Zaki, and Kamal Eldahshan. "A new deep learning-based methodology for video deepfake detection using XGBoost." *Sensors* 21, no. 16 (2021): 5413.
- [12] Tolosana, Ruben, Ruben Vera-Rodriguez, Julian Fierrez, Aythami Morales, and Javier Ortega-Garcia. "Deepfakes and beyond: A survey of face manipulation and fake detection." *Information Fusion* 64 (2020): 131-148.
- [13] De Lima, Oscar, Sean Franklin, Shreshtha Basu, Blake Karwoski, and Annet George. "Deepfake detection using spatiotemporal convolutional networks." *arXiv preprint arXiv:2006.14749* (2020).
- [14] Khalil, Hady A., and Shady A. Maged. "Deepfakes creation and detection using deep learning." In *2021 International Mobile, Intelligent, and Ubiquitous Computing Conference (MIUCC)*, pp. 1-4. IEEE, 2021.
- [15] Suratkar, Shraddha, and Faruk Kazi. "Deep fake video detection using transfer learning approach." *Arabian Journal for Science and Engineering* 48, no. 8 (2023): 9727-9737.
- [16] Jaiswal, Gaurav. "Hybrid recurrent deep learning model for deepfake video detection." In *2021 IEEE 8th Uttar Pradesh section international conference on electrical, electronics and computer engineering (UPCON)*, pp. 1-5. IEEE, 2021.
- [17] Shende, Atharva. "Using deep learning to detect deepfake videos." *Turkish Journal of Computer and Mathematics Education (TURCOMAT)* 12, no. 11 (2021): 5012-5017.
- [18] Mitra, Alakananda, Saraju P. Mohanty, Peter Corcoran, and Elias Kougianos. "A novel machine learning based method for deepfake video detection in social media." In *2020 IEEE international symposium on smart electronic systems (iSES)(formerly iNiS)*, pp. 91-96. IEEE, 2020.
- [19] Abbas, Fakhar, and Araz Taeihagh. "Unmasking deepfakes: A systematic review of deepfake detection and generation techniques using artificial intelligence." *Expert Systems With Applications* (2024): 124260.
- [20] Mitra, Alakananda, Saraju P. Mohanty, Peter Corcoran, and Elias Kougianos. "A machine learning based approach for deepfake detection in social media through key video frame extraction." *SN Computer Science*

**International Conference on Advances in Science and Engineering (ICASE2025)**

2, no. 2 (2021): 98.

[21] Awotunde, Joseph Bamidele, Rasheed Gbenga Jimoh, Agbotiname Lucky Imoize, Ak- eem Tayo Abdulrazaq, Chun-Ta Li, and Cheng-Chi Lee. "An enhanced deep learning- based deepfake video detection and classification system." *Electronics* 12, no. 1 (2022): 87.

[22] Taeb, Maryam, and Hongmei Chi. "Comparison of deepfake detection techniques through deep learning." *Journal of Cybersecurity and Privacy* 2, no. 1 (2022): 89-106.

[23] Kim, Minha, Shahroz Tariq, and Simon S. Woo. "Fretal: Generalizing deepfake detection using knowledge distillation and representation learning." In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 1001-1012. 2021.

[24] Biswas, Adeep, Debayan Bhattacharya, and Kakelli Anil Kumar. "DeepFake detection using 3D-Xception net with discrete Fourier transformation." *Journal of Information Systems and Telecommunication (JIST)* 3, no. 35 (2021): 161.

[25] Hussain, Shehzeen, Paarth Neekhara, Malhar Jere, Farinaz Koushanfar, and Julian McAuley. "Adversarial deepfakes: Evaluating vulnerability of deepfake detectors to adversarial examples." In *Proceedings of the IEEE/CVF winter conference on applications of computer vision*, pp. 3348-3357. 2021.

[26] Andreas Rössler, D. Cozzolino, L. Verdoliva, C. Riess, Justus Thies, and M. Nießner. "FaceForensics++: Learning to Detect Manipulated Facial Images." *IEEE International Conference on Computer Vision*, 2019.

[27] Changjin Wang, Hamid R. Sharifzadeh, Soheil Varastehpour, and I. Ardekani. "Analysis and Comparison of Deepfakes Detection Methods for Cross-Library Generalisation." *Conference on Privacy, Security and Trust*, 2023.

[28] Chenhao Lin, Jingyi Deng, Peng Hu, Chao Shen, Qianqian Wang, and Qi Li. "Towards Benchmarking and Evaluating Deepfake Detection." *IEEE Transactions on Dependable and Secure Computing*, 2022.

[29] I. Masi, Aditya Killekar, R. Mascarenhas, Shenoy Pratik Gurudatt, and Wael AbdAlmageed. "Two- Branch Recurrent Network for Isolating Deepfakes in Videos." *European Conference on Computer Vision*, 2020. Kaede Shiohara, and T. Yamasaki. "Detecting Deepfakes with Self-Blended Images." *Computer Vision and Pattern Recognition*, 2022.

[30] Pavel Korshunov, and S. Marcel. "Improving Generalization of Deepfake Detection With Data Farming and Few-Shot Learning." *IEEE Transactions on Biometrics Behavior and Identity Science*, 2022.

[31] Ricard Durall, M. Keuper, F. Pfreundt, and J. Keuper. "Unmasking DeepFakes with Simple Features." *arXiv.org*, 2019.

[32] Sohail Ahmed Khan, and Duc-Tien Dang-Nguyen. "Deepfake Detection: Analyzing Model Generalization Across Architectures, Datasets, and Pre-Training Paradigms." *IEEE Access*, 2024.

[33] U. Ciftci, and Ilke Demir. "FakeCatcher: Detection of Synthetic Portrait Videos Using Biological Signals." *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 2019.

[34] Yang He, Ning Yu, M. Keuper, and Mario Fritz. "Beyond the Spectrum: Detecting Deepfakes via Re-Synthesis." *International Joint Conference on Artificial Intelligence*, 2021.

# Real-Time Human Blood Bacteria Identification System Using a Color Sensor & IOT

<sup>1</sup>Karina Rahate, <sup>2</sup>Karishma Bhagat, <sup>3</sup>Tejaswini Kakde, <sup>4</sup>Nandini Marbate, <sup>5</sup>Ayush Waghulkar, <sup>6</sup>Ms. S.S. Dhanvijay

<sup>1</sup> Karina Rahate Priyadarshini Bhagwati College of Engineering Nagpur

<sup>2</sup> Karishma Bhagat Priyadarshini Bhagwati College of Engineering Nagpur

<sup>3</sup>Ms. S.S. Dhanvijay, Dept. of Electronics & Communication Engineering, Priyadarshini Bhagwati college of Engineering, Maharashtra, India

**Abstract** - The Human Blood Bacteria Identification System is an IoT-based biomedical project designed to detect bacterial infections like bacteremia and fungemia in human blood samples. The system uses a TCS3200 color sensor to identify color changes in blood, indicating the presence of bacteria. The NodeMCU ESP8266 microcontroller processes the data and displays the result on an LCD screen. It also sends real-time alerts to cloud platforms for remote monitoring. This system provides a faster, cost-effective, and portable solution compared to traditional blood culture methods, making it ideal for use in hospitals, rural areas, and emergency healthcare services.

**KeyWords:** Blood Bacteria Identification, IoT- Based Detection, Color Sensor, NodeMCU, Bacteremia, Biomedical System, etc.

## I. Introduction

The Human Blood Bacteria Identification System is an innovative biomedical project aimed at detecting bacterial infections in human blood samples using advanced sensor technology and Internet of Things (IoT) applications. Its primary goal is to provide a cost-effective, rapid, and efficient method for identifying life-threatening conditions like bacteremia and fungemia, which can be fatal if not detected early.

With the growing concern over antibiotic resistance and the rise of infectious diseases, quick detection of bacterial infections has become increasingly vital in healthcare. Traditional diagnostic methods, such as blood culture tests, are time-consuming (taking 24-48 hours) and require complex laboratory procedures. In response, this system offers a real-time, automated solution that can quickly and accurately identify bacterial infections.

The system is composed of a NodeMCU ESP8266 microcontroller, a TCS3200 color sensor, an LCD display, an LED light source, and a power supply regulator (7805). Blood samples are placed in a testing chamber where the

TCS3200 sensor detects color changes caused by bacterial infections. These color variations are then converted into electrical signals, which the NodeMCU processes to identify the presence of bacteria. The results are displayed on the LCD screen and sent to cloud platforms via Wi-Fi for remote monitoring.

This system provides several advantages, including faster detection, affordability, portability, and real-time IoT alerts. It is particularly beneficial for use

in rural healthcare centers, hospitals, and emergency medical services. With future advancements, this system could be enhanced to detect a broader range of bacterial infections and improved accuracy using artificial intelligence.

The Human Blood Bacteria Identification System marks a significant advancement in biomedical diagnostics, enabling early detection of bacterial infections and reducing the risk of potentially fatal conditions in patients.

### 1.1 Need for The Project

Bacterial infections in the bloodstream can lead to serious health complications, such as sepsis, which can result in organ failure or even death if not promptly diagnosed and treated. Early detection of these infections is crucial for initiating appropriate medical interventions. However, traditional diagnostic methods are often time-consuming, costly, and require highly trained professionals.

To overcome these challenges, this project aims to develop an IoT-based system for identifying bacterial infections in blood samples, providing immediate results without the need for complex laboratory setups. By utilizing Color Sensor Technology (TCS3200) in combination with the NodeMCU (ESP8266), the system detects the presence of bacteria in blood samples through color changes, offering a quick and efficient solution for bacterial identification.

### 1.2 Bloodstream Infection (BSI)

A bloodstream infection (BSI) occurs when harmful bacteria, fungi, or viruses enter the bloodstream and spread throughout the body. These infections can lead to severe complications such as sepsis, organ failure, and even death if not

## **International Conference on Advances in Science and Engineering (ICASE2025)**

detected and treated promptly. Among the most common forms of BSI are bacteremia (bacteria in the blood) and fungemia (fungal infection in the blood).

Bloodstream infections pose a significant healthcare challenge worldwide. They are particularly dangerous for individuals with compromised immune systems, such as critically ill patients, the elderly, and those undergoing invasive medical procedures. Early detection and rapid diagnosis are crucial in managing BSIs, as delays in treatment can lead to life-threatening complications.

### **1.3 Introduction Role of Enzymes**

Enzymes play a crucial role in the detection of bacteria and fungi in human blood. In conventional blood culture systems, enzymatic reactions facilitate the growth, identification, and differentiation of microorganisms. For IoT-based detection systems like yours, enzyme-based blood culture media can serve as a reference standard for validating color sensor readings.

## **II. Literature Survey**

1. **Traditional Blood Culture Methods:** Traditional blood culture methods are widely used for detecting bacterial infections in human blood samples. According to WHO reports (2020), blood culture is the gold standard for detecting Bacteremia and Fungemia. However, this method takes 24-48 hours or more to deliver results and requires laboratory infrastructure and skilled professionals, making it less effective for emergency cases and rural areas. **Limitation:** Time-consuming, costly, and not portable.

2. **Automated Blood Culture Systems:**

Modern automated systems like the BACTEC™ and BacT/ALERT® systems have improved the speed and accuracy of blood infection detection. Research by John Hopkins University (2021) shows that these systems reduce detection time to 12-24 hours but still require expensive laboratory setups and high maintenance costs. **Limitation:** High cost, requires laboratory setup. 3. **Colorimetric Bacterial Detection Systems:** Recent studies indicate that bacterial infections can be identified through Colorimetric Analysis. According to Wang et al. (2022), bacterial metabolism in blood samples causes a color change due to biochemical reactions, making color sensors an effective method for detecting infections. **Limitation:** Limited accuracy without advanced sensors. 4. **IoT-Based Medical Systems:** IoT-based healthcare systems have gained popularity in recent years. According to Patel et al. (2023), IoT systems allow remote monitoring of patient health data in real-time. These systems are widely used for glucose level monitoring, heart rate detection, and temperature measurement. **Limitation:** Network

dependency and data security.

5. **Color Sensor TCS3200 in Biomedical Applications:** The TCS3200 Color Sensor has been successfully used in biomedical applications for liquid Color detection. Research by Gupta et al. (2023) demonstrated that the sensor could detect various colors in biological samples with high accuracy. The sensor converts color intensity into frequency signals, which can be processed by microcontrollers like NodeMCU ESP8266. **Limitation:** Affected by external light. 6. **Conventional Methods:** Blood culture remains the gold standard for bacterial identification, involving the incubation of blood samples in culture media to allow bacterial growth, followed by Gram staining and biochemical tests. However, this method is time-consuming, taking 24-72 hours for results, and is susceptible to false negatives and contamination risks. Microscopy and staining techniques, such as Gram staining, provide a preliminary indication of bacterial presence but lack specificity and sensitivity. 7. **Molecular and Genomic Approaches:** To overcome these limitations, molecular and genomic techniques such as Polymerase Chain Reaction (PCR) and Next-Generation Sequencing (NGS) have been introduced. PCR-based methods amplify bacterial DNA for rapid detection and identification, offering high specificity and sensitivity within 2-6 hours. Multiplex PCR allows simultaneous detection of multiple bacterial species, while NGS provides comprehensive genomic analysis, identifying bacterial species and antibiotic resistance genes with high accuracy. Despite their advantages, these methods require specialized equipment and trained personnel, limiting their accessibility. 8. **Biosensor-Based Approaches:** Biosensors, including electrochemical, optical, and nanotechnology-based biosensors, integrate biological recognition elements with electronic systems to detect bacterial markers. These technologies offer rapid and portable diagnostics but require further clinical validation. 9. **Bloodstream infections (BSIs) caused by bacterial pathogens are a major global health concern, requiring rapid and accurate identification for effective treatment. Conventional methods, such as blood cultures, suffer from long processing times, leading to delays in appropriate antibiotic administration. Emerging technologies aim to enhance the speed and accuracy of bacterial identification through molecular techniques, artificial intelligence, and biosensors. 10.**

Biosensor-based approaches offer rapid and portable bacterial identification solutions. Banerjee et al. (2019) developed an electrochemical biosensor capable of detecting bacterial pathogens in minutes, while Singh et al. (2021) introduced a nanotechnology-based biosensor for enhanced specificity. Optical biosensors, as examined by Kim et al. (2017), utilize fluorescence markers for high-accuracy bacterial detection, making them promising candidates for point-of-care diagnostics.

11. **Emerging technologies further enhance diagnostic capabilities. Chen et al. (2019) investigated CRISPR-based diagnostics, providing ultra-rapid and highly specific**

## **International Conference on Advances in Science and Engineering (ICASE2025)**

bacterial identification. Gupta et al. (2021) studied microfluidic lab-on-a-chip devices, enabling miniaturized and cost-effective blood testing. Patel et al. (2018) explored wearable biosensors for real-time monitoring of bloodstream infections, presenting a futuristic approach to continuous infection surveillance. 12. Bacterial Detection in Blood Johnson et al. (2019) proposed an automated blood infection detection system using an optical sensor and found that optical sensors can detect microbial growth by analyzing changes in the liquid sample's color and density, but the system required high-cost instruments [23]. 13. R. K. Sharma et al. (2020) developed a spectrophotometry-based bacterial detection system that uses light absorption principles to detect the growth of bacteria in liquid samples. However, the system had low portability and was not suitable for real-time detection [24]. 14. IoT-Based Health Monitoring Systems V. Kumar et al. (2023) developed an IoT-based temperature and heart rate monitoring system using NodeMCU. The study showed that IoT systems provide real-time data transmission to cloud platforms for remote diagnosis [25]. 15. D. Patel et al. (2023) proposed an IoT-enabled glucose monitoring system that sends patient health data to doctors remotely. This study demonstrated that IoT systems improve medical response time in emergency cases.

### **III. Components Used**

#### **3.1 NodeMCU**

Node MCU is a low-cost open source IOT platform. It initially included firmware which runs on the ESP8266 Wi-Fi SoC from Espressif Systems, and hardware which was based on the ESP-12 module. Later, support for the ESP32 32-bit MCU was added. The firmware uses the Lua scripting language. The firmware is based on the Elua project, and built on the Espressif Non-OS SDK for ESP8266. It uses many open-source projects, such as lua-cjson [10] and SPIFFS.[11] Due to resource constraints, users need to select the modules relevant for their project and build a firmware tailored to their needs. Support for the 32-bit ESP32 has also been implemented.

The prototyping hardware typically used is a circuit board functioning as a dual in-line package (DIP) which integrates a USB controller with a smaller surface-mounted board containing the MCU and antenna. The choice of the DIP format allows for easy prototyping on breadboards. The design was initially based on the ESP-12 module of the ESP8266, which is a Wi-Fi SoC integrated with a Tensilica Xtensa LX106 core, widely used in IoT applications. ESP8266 is Wi-Fi enabled system on chip (SoC) module developed by Espressif system.

#### **3.2. LCD**

LCD modules are very commonly used in most embedded

projects, the reason being its cheap price, availability and programmer friendly. Most of us would have come across these displays in our day-to-day life, either at PCO's or calculators. The appearance and the pin outs have already been visualized above now let us get a bit technical.

16×2 LCD is named so because; it has 16 Columns and 2 Rows. There are a lot of combinations available like, 8×1, 8×2, 10×2, 16×1, etc. but the most used one is the 16×2 LCD. So, it will have (16×2=32) 32 characters in total and each character will be made of 5×8 Pixel Dots.

#### **3.3. TCS3200 Color Sensor**

TCS3200 Color Sensor is a complete color detector, including a TAOS TCS3200 RGB sensor chip and

4 white LEDs. The TCS3200 can detect and measure a nearly limitless range of visible colors. Applications include test strip reading, sorting by color, ambient light sensing and calibration, and color matching, to name just a few. The TCS3200 has an array of photodetectors, each with either a red, green, or blue filter, or no filter (clear). The filters of each color are distributed evenly throughout the array to eliminate location bias among the colors. Internal to the device is an oscillator which produces a square-wave output whose frequency is proportional to the intensity of the chosen color.

### **IV. Proposed Methodology**

The Human Blood Bacteria Identification System is designed to detect bacterial infections in human blood samples using IoT technology and colorimetric analysis. The proposed methodology

outlines the step-by-step process for developing and implementing the system.

#### **4.1. Methodology Steps**

1. Sample Collection: A small amount of human blood sample is collected and placed into the testing chamber. The chamber contains reagents that cause a color change in the presence of bacteria.

2. Color Detection using TCS3200 Sensor: The TCS3200 color sensor detects the color variation of the blood sample caused by the chemical reaction.

The sensor converts the detected color into electrical signals in the form of frequency values (RGB).

3. Signal Processing using NodeMCU ESP8266: The NodeMCU microcontroller reads the frequency signals from the TCS3200 sensor. The microcontroller processes the signals and compares them with pre-stored threshold values to determine whether bacteria are present or not.

4. Result Display on LCD: The result is displayed on a 16x2 LCD screen:

- If bacteria are detected, "Infected."
- If no bacteria are detected, "Not Infected."

**International Conference on Advances in Science and Engineering (ICASE2025)**

5. Alert System: If bacteria are detected, the system automatically sends an alert notification to the user or healthcare professional via SMS or email.

**V. WORKING**

**5.1. Working Explanation:**

1. Blood Sample Placement: The blood sample is placed in a small transparent container under the Color Sensor TCS3200. The sensor is used to detect

the color variation in the sample, which represents the presence of bacteria or fungi.

2. Color Detection by TCS3200 Sensor: The TCS3200 color sensor detects the intensity of red, green, and blue (RGB) colors. Bacterial infections like bacteremia or fungemia can change the color of the blood due to the metabolic by-products of bacteria or fungi.

Normal Blood → No significant color change

Infected Blood → Color changes (dark red or dark brown tint)

3. Signal Processing with NodeMCU: The sensor data is sent to the NodeMCU (ESP8266) microcontroller, which processes the RGB values and determines whether the blood is infected or not based on predefined threshold values.

4. Displaying Result on LCD: The final result (infected or non-infected) is displayed on the 16x2 LCD display.

5. IoT Data Transmission: The NodeMCU transmits the data to an IoT Cloud Platform through Wi-Fi, where doctors or users can remotely monitor the blood test results.

6. Alert System: If the blood is infected, an LED indicator will glow, and the data will be updated on the cloud with an alert message.

**VI. Result**

The implementation of the Human Blood Bacteria Identification System Using IoT has demonstrated significant improvements in the early detection of bacterial infections in human blood. The data obtained from multiple test samples confirm that the TCS3200 color sensor effectively identifies bacterial presence by detecting color variations in the blood sample. The integration of NodeMCU enables real-time data transmission to the Ubidots cloud platform, allowing for continuous monitoring and remote accessibility.

The system has shown high accuracy in bacterial detection, reducing the time required for traditional culture-based diagnosis. Additionally, the real-time processing capabilities have enhanced the efficiency of infection detection, supporting faster decision-making in medical

applications. The LCD display provides instant visual feedback, making the system user-friendly. Furthermore, the use of a 7805-voltage regulator ensures a stable power supply, making the system energy-efficient and cost-effective.

Overall, the results validate the reliability, affordability, and efficiency of the developed system in detecting bacteremia and fungemia, paving the way for IoT-driven biomedical innovations in healthcare.

The Human Blood Bacteria Identification System is successfully designed and implemented to detect bacterial infections in human blood samples using IoT technology and colorimetric analysis. The system provides real-time detection of bacteria by analyzing color variations in the blood sample through the TCS3200 Color Sensor and displays the result on an LCD screen. The processed data is transmitted to cloud platforms for remote monitoring, enhancing the efficiency of the diagnosis process.

Sample Type	Color Detected	Bacteria Presence	Result on LCD	IoT Alert Status
Normal Blood Samples	Red/Light Red	Absent	Not Infected	Alert Sent
Infected Blood Samples	Dark Red/Dark Brownish	Presence	Infected	Alert Sent
Non-Infected Blood	Red/Light Red	Absent	Not Infected	Alert Sent

**VII. Conclusions**

The Human Blood Bacteria Identification System is a revolutionary step in the biomedical field, offering a faster, cost-effective, and reliable solution for detecting bacterial infections in blood samples. This project bridges the gap between traditional diagnostic methods and modern IoT-based healthcare systems. The system's ability to provide real-time, remote monitoring makes it a valuable tool for improving global healthcare, especially in remote and rural areas where access to laboratory facilities is limited.

By implementing this system, early detection of bacterial infections will significantly reduce mortality rates, improve patient outcomes, and contribute to the overall advancement of medical diagnostics.

**References**

[1] Greisen K, Loeffelholz M, Purohit A, Leong D. PCR primers and probes for the 16S rRNA gene of most species of pathogenic bacteria, including bacteria found in cerebrospinal fluid. *J Clin Microbiol.* 1994; 32:335–351. doi:

**International Conference on Advances in Science and Engineering (ICASE2025)**

- 10.1128/jcm.32.2.335-351.1994.
- [2] Laforgia N, Coppola B, Carbone R, Grassi A, Mautone A, Lolascon A. Rapid detection of neonatal sepsis using polymerase chain reaction. *Acta Paediatr.* 1997; 86:1097–1099. doi: 10.1111/j.1651-2227.1997.tb14815.x.
- [3] Davis T E, Fuller D D. Direct identification of bacterial isolates in blood cultures by using a DNA probe. *J Clin Microbiol.* 1991; 29:2193–2196. doi: 10.1128/jcm.29.10.2193-2196.1991.
- [4] Beekman SE, Deikema D, Chapin K, Doern GV. Effects of rapid detection of bloodstream infections on length of hospitalization and hospital charges. *J Clin Microbiol.* 2003; 41:3119–3125. doi: 10.1128/JCM.41.7.3119-3125.2003.
- [5]. Mehta MS, Paul S, Thomson R, Kaul K, Peterson LR. Identification of Staphylococcus species directly from positive blood culture broth by use of molecular and conventional methods. *J Clin Microbiol.* 2009; 47:1082–1086. doi: 10.1128/JCM.01850-08.
- [6]. Lucignano B, Ranno S, Liesenfeld O, Pizzorno B, Putigani L, et al. Multiplex PCR allows rapid and accurate diagnosis of bloodstream infections in newborns and children with suspected sepsis. *J Clin Microbiol.* 2011; 49:2252–2258. doi: 10.1128/JCM.02460-10.
- [7]. Ferroni A, Suarez S, Beretti J, Dauphin B, Bille E, et al. Real-time identification of bacteria and Candida species in positive blood culture broths by matrix-assisted laser desorption ionization-time of flight mass spectrometry. *J Clin Microbiol.* 2010; 48:1542–1548. doi: 10.1128/JCM.02485-09.
- [8]. Szabados F, Michels M, Kaase M, Gaterman S. The sensitivity of direct identification from positive BacT/ALERT™ (bioMérieux) blood culture bottles by matrix-assisted laser desorption ionization time-of-flight mass spectrometry is low. *Clin Microbiol Infect.* 2010; 17:192–195. doi: 10.1111/j.1469-0691.2010.03229.x.
- [9]. Petti CA, Woods C, Reller LB. Streptococcus pneumoniae antigen test using positive blood culture bottles as an alternative method to diagnose pneumococcal bacteremia. *J Clin Micro.* 2005; 43:2510–2512. doi: 10.1128/JCM.43.5.2510-2512.2005.
- [10]. M. Bruins, A. Bos, P. L. Petit, K. Eadie, A. Rog, R. Bos, et al., "Device-independent real-time identification of bacterial pathogens with a metal oxide-based olfactory sensor", *Eur. J. Clin. Microbiol. Infect. Dis.*, vol. 28, pp. 775-780, Jul. 2009.
- [11]. M. Holmberg, F. Gustafsson, E. G. Hrnsten, F. Winquist, L. E. Nilsson, L. Ljung, et al., "Feature extraction from sensor data on bacterial growth", *Biotechnol. Tech.*, vol. 12, no. 4, pp. 319- 324, 2004.
- [12]. Ferraz, A., Carvalho, V., & Soares, F. (2010). Development of a human blood type detection automatic system. *Procedia Engineering*, 5, 496-499.
- [13]. Panpatte, S. G., Pande, A. S., & Kale, R. K. (2017). Application of image processing for blood group detection. *International Journal of Electronics, Communication and Soft Computing Science & Engineering (IJECSSE)*, 61-65.
- [14]. Zohra, B. F., & Mohamed, B. (2009). Automated diagnosis of retinal images using the Support Vector Machine (SVM). *Faculte des Science, Department of Informatique, USTO, Algerie.*
- [15]. Divina, P. D. C. Felices, J. P. T. Hortinela IV, C., Fausto, J. C. Valiente, F. L. & Balbin, J. R. (2020, September). Classification of red blood cell morphology using image processing and support vector machine. In *Proceedings of the 2020 10th International Conference on Biomedical Engineering and Technology* (pp. 22-27).
- [16]. Alpern, E. R., E. A. Alessandrini, L. M. Bell, K. N. Shaw, and K. L. McGowan. 2000. Occult bacteremia from a pediatric emergency department: current prevalence, time to detection, and outcome. *Pediatrics* 106:505-511.
- [17]. Ammann, R. A., A. Hirt, A. R. Luthy, and C. Aebi. 2003. Identification of children presenting with fever in chemotherapy-induced neutropenia at low risk for severe bacterial infection. *Med. Pediatr. Oncol.* 41:436-443.
- [18]. Bandyopadhyay, S., J. Bergholte, C. D. Blackwell, J. R. Friedlander, and H. Hennes. 2002. Risk of serious bacterial infection in children with fever without a source in the post-Haemophilus influenzae era when antibiotics are reserved for culture-proven bacteremia. *Arch. Pediatr. Adolesc. Med.* 156:512-517.
- [19]. Bates, D. W., and T. H. Lee. 1992. Rapid classification of positive blood cultures. Prospective validation of a multivariate algorithm. *JAMA* 267:1962-1966.
- [20]. Berger, R. M., M. Y. Berger, H. A. van Steensel-Moll, G. Dzoljic-Danilovic, and G. Derksen-Lubsen. 1996. A predictive model to estimate the risk of serious bacterial infections in febrile infants. *Eur. J. Pediatr.* 155:468-473.
- [21]. Birnbaumer, D. M. 24 November 2004, posting date. Blood cultures aren't useful for managing immunocompetent CAP inpatients. *J.*

**International Conference on Advances in Science and Engineering (ICASE2025)**

Watch Emerg. Med. [Online.] <http://emergency-medicine.jwatch.org/cgi/content/full/2004/1124/1>

- [22]. Campbell, S. G., T. J. Marrie, R. Anstey, S. Ackroyd-Stolarz, and G. Dickinson. 2003. Utility of blood cultures in the management of adults with community acquired pneumonia discharged from the emergency department. *Emerg. Med. J.* 20:521- 523.
- [23]. Johnson et al., "Automated Blood Infection Detection System," *Biomedical Research Journal*, 2019.
- [24]. R. K. Sharma et al., "Spectrophotometry-Based Bacterial Detection System," *International Journal of Biomedical Science*, 2020.
- [25]. K. Jain et al., "IoT-Based Blood Bacteria Detection System," *International Journal of Biomedical Engineering*, 2023.