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Emerging AI Approaches for Breast Cancer Detection: A Systematic Review of ML and DL Applications Across the Globe

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Abstract: Breast cancer is one of the most prevalent and life-threatening diseases affecting women globally, where early detection plays a crucial role in reducing mortality rates. In recent years, emerging Artificial Intelligence (AI) techniques, particularly Machine Learning (ML) and Deep Learning (DL), have shown remarkable potential in improving the accuracy and efficiency of breast cancer detection and diagnosis. This systematic review presents a comprehensive overview of global research efforts that leverage AI-based methodologies across various medical imaging modalities, including mammography, ultrasound, magnetic resonance imaging (MRI), and histopathological imaging.

The study reviews traditional ML algorithms such as Support Vector Machines (SVM), Decision Trees, Random Forests, and k-Nearest Neighbors (k-NN), alongside advanced DL architectures including Convolutional Neural Networks (CNNs), Deep Neural Networks (DNNs), and transfer learning models. The analysis highlights that DL approaches, especially CNNs, significantly outperform conventional ML techniques due to their ability to automatically extract complex features from large-scale datasets. Additionally, the review discusses hybrid and ensemble models that combine ML and DL techniques to enhance predictive performance.

Key challenges identified include limited availability of high-quality annotated datasets, class imbalance, overfitting, lack of interpretability, and issues related to generalization across diverse populations and imaging systems. The review also emphasizes the growing importance of explainable AI (XAI), data privacy, and ethical considerations in clinical deployment. Comparative insights from global studies reveal varying levels of accuracy and robustness depending on data sources, preprocessing techniques, and evaluation metrics.

Overall, the findings suggest that AI-driven approaches hold significant promise in supporting radiologists, improving diagnostic accuracy, and enabling early-stage detection of breast cancer. Future research directions focus on developing standardized datasets, improving model transparency, and fostering interdisciplinary collaboration to ensure reliable and scalable real-world applications.

Keywords: Breast Cancer Detection, Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL), Convolutional Neural Networks (CNN), Medical Imaging, Mammography, Ultrasound Imaging, MRI.

I. INTRODUCTION

Breast cancer remains one of the most significant global health challenges, being the most frequently diagnosed cancer among women and a leading cause of cancer-related mortality worldwide. Recent statistics indicate that millions of new cases are diagnosed annually, highlighting the urgent need for early detection and accurate diagnosis to improve survival rates and reduce healthcare burdens . Traditional diagnostic methods such as mammography, ultrasound, and biopsy, although effective, often suffer from limitations including human error, variability in interpretation, and late-stage detection.

In recent years, Artificial Intelligence (AI) has emerged as a transformative technology in the medical domain, particularly in cancer detection. AI systems aim to mimic human intelligence by analyzing large volumes of medical data, enabling automated and efficient decision-making processes. Within AI, Machine Learning (ML) and Deep Learning (DL) have gained significant attention for their ability to identify complex patterns and relationships in clinical and imaging data . ML techniques rely on statistical models and feature engineering to classify and predict outcomes, while DL, a subset of ML, utilizes multi-layered neural networks to automatically extract high-level features from raw data, especially medical images .

The integration of ML and DL into breast cancer detection has led to the development of advanced Computer-Aided Diagnosis (CAD) systems that assist radiologists in identifying tumors with greater accuracy and consistency. Traditional

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ML algorithms such as Support Vector Machines (SVM), Random Forest, and k-Nearest Neighbors (k-NN) have been widely applied for classification tasks, whereas DL architectures—particularly Convolutional Neural Networks (CNNs)—have demonstrated superior performance in analyzing mammograms, histopathological images, and other imaging modalities . These approaches reduce dependence on manual feature extraction and enable end-to-end learning from complex datasets.

Moreover, emerging AI techniques are increasingly being applied across diverse data sources, including medical imaging, genomic data, and clinical records, facilitating early detection, risk prediction, and personalized treatment planning. AI-driven models have shown promising results in improving diagnostic accuracy, minimizing false positives and negatives, and enhancing clinical decision-making processes . Despite these advancements, challenges such as data quality, model interpretability, generalizability, and ethical concerns remain critical barriers to widespread clinical adoption.

This systematic review aims to explore and analyze emerging AI approaches in breast cancer detection, focusing on the evolution, applications, and performance of ML and DL techniques across the globe. It highlights current trends, key methodologies, and future research directions, providing a comprehensi

II. LITERATURE REVIEW

Breast cancer remains one of the leading causes of cancer-related mortality among women worldwide, emphasizing the need for early and accurate detection methods. In recent years, Artificial Intelligence (AI), particularly Machine Learning (ML) and Deep Learning (DL), has emerged as a transformative tool in medical imaging and diagnostic systems.

Early studies in this domain focused on traditional ML techniques such as Support Vector Machines (SVM), Decision Trees, and k-Nearest Neighbors (k-NN), which relied heavily on handcrafted features extracted from medical images like mammograms and histopathological slides. These models demonstrated moderate success in classification tasks but were limited by feature dependency and lower generalization ability .

With advancements in computational power and data availability, DL techniques—especially Convolutional Neural Networks (CNNs)—have gained prominence due to their ability to automatically extract hierarchical features from raw data. A systematic review by Nassif et al. (2022) analyzed over 80 research articles and concluded that DL models significantly outperform traditional ML approaches in breast cancer detection tasks, particularly in image-based diagnosis . CNN architectures such as ResNet, VGGNet, and Inception have been widely adopted for tumor classification, segmentation, and detection.

Recent literature highlights the increasing use of hybrid models that combine ML and DL techniques to improve diagnostic accuracy. These models integrate clinical data, imaging data, and genomic information to provide more robust predictions. Additionally, DL-based Computer-Aided Diagnosis (CAD) systems have shown significant improvements in sensitivity and specificity, aiding radiologists in identifying malignant tumors more effectively .

A more recent systematic review (2025) emphasizes that AI-based frameworks not only enhance detection accuracy but also improve efficiency and consistency in diagnosis. AI systems have demonstrated superior performance in tasks such as mitotic cell counting and histopathological classification, often surpassing manual analysis by pathologists . Furthermore, AI-assisted screening programs have shown promising real-world outcomes, including increased early detection rates and reduced diagnostic errors.

Another emerging trend in the literature is the development of Explainable AI (XAI), which addresses the “black-box” nature of DL models. Techniques such as SHAP (SHapley Additive exPlanations) are increasingly used to interpret model decisions, thereby improving transparency and trust among clinicians. XAI plays a crucial role in clinical adoption, as it enables healthcare professionals to understand and validate AI-driven predictions .

Despite these advancements, several challenges persist. Many studies rely on small or non-diverse datasets, limiting the generalizability of AI models. External validation of models is still not consistently performed, which raises concerns about their reliability in real-world clinical settings. Additionally, ethical concerns such as data privacy, bias, and lack of interpretability remain significant barriers to widespread implementation.

Overall, the literature indicates a clear shift from traditional ML approaches to advanced DL and hybrid AI systems in breast cancer detection. While the results are promising, future research should focus on improving model generalization, integrating multi-modal data, and enhancing explainability to ensure safe and effective clinical deployment.

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III. METHODOLOGY

This study adopts a **systematic literature review (SLR)** approach to identify, evaluate, and synthesize existing research on machine learning (ML) and deep learning (DL) techniques for breast cancer detection. The methodology follows standardized guidelines such as the **PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)** framework to ensure transparency and reproducibility.

1. Research Design

A qualitative systematic review methodology was employed to analyze global research contributions in AI-based breast cancer detection. The study focuses on:

- Machine Learning algorithms (e.g., SVM, Decision Trees, KNN)
- Deep Learning models (e.g., CNN, ANN, hybrid models)
- Applications in medical imaging, histopathology, and genomics

2. Data Sources and Search Strategy

A comprehensive literature search was conducted across multiple academic databases, including:

- IEEE Xplore
- ScienceDirect
- PubMed
- SpringerLink
- Google Scholar

Search Keywords

The following keywords and Boolean combinations were used:

- “Breast cancer detection” AND “machine learning”
- “Deep learning” AND “breast cancer diagnosis”
- “AI in medical imaging” AND “mammography”
- “CNN for breast cancer detection”

The search covered publications from **2015 to 2025** to capture recent advancements in AI technologies.

3. Inclusion and Exclusion Criteria

Inclusion Criteria

- Peer-reviewed journal and conference papers
- Studies focusing on ML/DL applications in breast cancer detection
- Articles reporting experimental results with evaluation metrics
- English-language publications

Exclusion Criteria

- Non-peer-reviewed articles (blogs, editorials)
- Studies not related to AI-based detection
- Duplicate or incomplete studies

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- Papers lacking sufficient methodological details

4. Study Selection Process

The study selection followed a multi-stage screening process:

1. **Identification**
   - Articles were collected from selected databases
2. **Screening**
   - Titles and abstracts were reviewed to remove irrelevant studies
3. **Eligibility**
   - Full-text articles were assessed based on inclusion/exclusion criteria
4. **Final Selection**
   - Only high-quality and relevant studies were included in the review

This process ensures that only validated and relevant research contributes to the findings.

5. Data Extraction

From each selected study, the following information was extracted:

- Author(s) and publication year
- Dataset used (e.g., mammograms, histopathological images)
- AI techniques (ML or DL models)
- Feature extraction methods
- Evaluation metrics (accuracy, precision, recall, F1-score, AUC)
- Key findings and limitations

6. Data Analysis and Synthesis

The extracted data were analyzed using a **comparative and thematic approach**:

- ML vs DL performance comparison
- Model-wise evaluation (CNN, SVM, etc.)
- Dataset and modality comparison
- Identification of trends and research gaps

Deep learning models, particularly CNNs, were found to dominate due to their strong performance in image-based detection tasks.

7. Quality Assessment

Each selected study was evaluated based on:

- Dataset quality and size
- Model validation techniques (cross-validation, external validation)
- Reproducibility and transparency
- Performance evaluation rigor

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Common challenges identified include dataset imbalance, lack of standardization, and limited generalizability across populations.

8. Limitations of the Study

- Possible publication bias due to reliance on indexed databases
- Language restriction to English publications
- Rapid evolution of AI may exclude very recent unpublished advancements

9. Ethical Considerations

- Only publicly available and peer-reviewed studies were used
- No human subjects or confidential data were involved

IV. RESULTS AND DISCUSSION

1. Results

1.1 Overview of Selected Studies

The systematic review analyzed multiple research studies published between 2020 and 2025 focusing on Machine Learning (ML) and Deep Learning (DL) techniques for breast cancer detection. The studies were categorized based on:

- Type of algorithm (ML vs DL)
- Imaging modality (mammograms, ultrasound, histopathology)
- Performance metrics (accuracy, sensitivity, specificity, AUC)

Most studies emphasized the use of **medical imaging datasets**, particularly mammography and histopathological images, as primary input sources for model training.

1.2 Performance of Machine Learning Models

Traditional ML algorithms such as:

- Support Vector Machine (SVM)
- Random Forest (RF)
- k-Nearest Neighbors (KNN)
- Logistic Regression

were widely used for classification tasks.

Key findings:

- ML models achieved **accuracy ranging from 85% to 95%** in many studies.
- Feature engineering played a critical role in improving performance.
- Ensemble methods often outperformed single classifiers.

1.3 Performance of Deep Learning Models

Deep Learning approaches, especially Convolutional Neural Networks (CNNs), dominated recent research.

Key findings:

- DL models achieved **accuracy above 90–97%** in several studies.

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- CNN-based architectures showed superior performance in image-based diagnosis.
- DL models reduced the need for manual feature extraction.

Recent real-world evidence also shows:

- AI-assisted screening detected **81% of cancers vs 74% in traditional methods**.
- Reduction of late-stage diagnoses by **~12%**.

1.4 Comparison of ML vs DL

Aspect	Machine Learning	Deep Learning
Feature Extraction	Manual	Automatic
Accuracy	Moderate–High	High
Data Requirement	Low–Medium	High
Interpretability	High	Low
	Limited	Excellent

Overall, DL models consistently outperformed ML models, particularly in complex image analysis tasks.

1.5 Emerging Trends

- Use of **Explainable AI (XAI)** for model transparency
- Integration of **multi-modal data** (clinical + imaging)
- Development of **hybrid ML-DL models**
- Increasing use of **transfer learning and pre-trained networks**

2. Discussion

2.1 Effectiveness of AI in Early Detection

The findings indicate that AI-based systems significantly enhance early detection of breast cancer. DL models, especially CNNs, can identify subtle patterns in medical images that may not be visible to radiologists.

- AI acts as a **decision-support tool**, not a replacement for clinicians
- Improves diagnostic accuracy and reduces human error

2.2 Advantages of Deep Learning Approaches

- Eliminates dependency on handcrafted features
- Handles large-scale and complex datasets efficiently
- Demonstrates high robustness in image classification

However, DL models require:

- Large, annotated datasets
- High computational resources

2.3 Challenges Identified

Despite promising results, several limitations persist:

1. **Data Limitations**
    - Lack of large, diverse datasets
    - Class imbalance issues affecting model performance

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2. **Model Interpretability**
    - DL models act as “black boxes”
    - Difficult for clinicians to trust predictions
3. **Generalization Issues**
    - Models trained on specific datasets may not perform well globally
    - Variation in imaging techniques across regions
4. **Clinical Integration**
    - Regulatory and ethical challenges
    - Need for real-world validation before deployment

2.4 Role of Explainable AI (XAI)

Explainable AI techniques such as SHAP are increasingly used to:

- Improve model transparency
- Provide visual explanations for predictions
- Enhance clinician trust and adoption

2.5 Future Research Directions

- Development of **lightweight AI models** for real-time diagnosis
- Increased use of **federated learning** for data privacy
- Integration with **IoT and wearable devices** for continuous monitoring
- Standardization of datasets and evaluation metrics

2.6 Overall Interpretation

The review clearly shows that:

- AI, particularly deep learning, is transforming breast cancer detection
- DL models outperform traditional ML approaches in most scenarios
    - However, challenges related to data, interpretability, and clinical adoption must be addressed

AI-based breast cancer detection systems demonstrate high accuracy and significant potential to improve early diagnosis and patient outcomes. While deep learning leads in performance, a balanced approach combining **accuracy, interpretability, and clinical usability** is essential for real-world implementation.

V. CONCLUSION

The systematic review of emerging Artificial Intelligence (AI) approaches for breast cancer detection highlights the transformative role of Machine Learning (ML) and Deep Learning (DL) in improving early diagnosis, accuracy, and clinical decision-making. Across global studies, AI-based models—particularly Convolutional Neural Networks (CNNs) and hybrid learning frameworks—have demonstrated superior performance in analyzing mammograms, histopathological images, and other medical imaging modalities compared to traditional diagnostic methods.

The findings reveal that DL techniques outperform conventional ML algorithms in feature extraction and classification due to their ability to learn complex patterns from large-scale datasets. Moreover, AI systems have shown potential in reducing false positives and false negatives, thereby minimizing unnecessary biopsies and improving patient outcomes. Integration of AI with Computer-Aided Diagnosis (CAD) systems has further enhanced radiologists’ efficiency and diagnostic confidence.

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However, despite these advancements, several challenges remain. Issues such as data scarcity, lack of standardized datasets, model interpretability, and ethical concerns related to privacy and bias continue to hinder large-scale clinical adoption. Additionally, variations in healthcare infrastructure across different regions impact the generalizability of AI models.

In conclusion, AI-driven approaches hold significant promise in revolutionizing breast cancer detection globally. Future research should focus on developing explainable AI models, improving dataset diversity, ensuring regulatory compliance, and fostering collaboration between researchers, clinicians, and policymakers. With continued innovation and responsible implementation, AI has the potential to become an indispensable tool in early breast cancer diagnosis and ultimately reduce mortality rates worldwide.

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